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Final Remedial Investigation Report

Volume I of III
Sections 1.0 through 8.0

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Phase II Remedial Investigation
Cold Regions Research and Engineering
Laboratory (CRREL)
Hanover, New Hampshire

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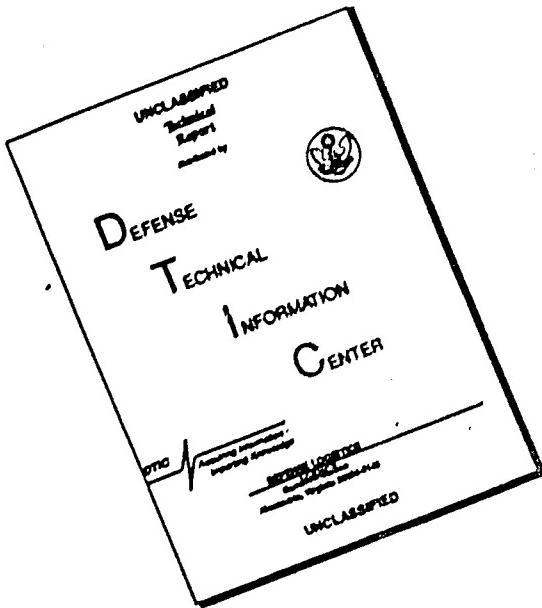
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**Final Remedial
Investigation Report**

Arthur D Little

**Volume I of III
Sections 1.0 through 8.0**

**Phase II Remedial
Investigation for Cold
Regions Research
and Engineering
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Hanover, NH**

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CRREL: RI Report
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Revision No.: 1
Date: March 18, 1994

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CRREL: RI Report
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List of Acronyms and Abbreviations

ADD	Average Daily Dose
ADL	Arthur D. Little, Inc.
AOC	Area of Concern
AST	Aboveground Storage Tank
ATV	Acoustic Televiwer
AWQC	Ambient Water Quality Criteria
bgs	Below Ground Surface
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Chemical of Potential Concern
CPF	Cancer Potency Factor
CRL	Certified Reporting Limit
CRREL	Cold Regions Research and Engineering Laboratory
DNAPL	Dense Non-Aqueous Phase Liquid
DQO	Data Quality Objective
EPA	U.S. Environmental Protection Agency
EPIC	Environmental Photographic Interpretation Center
FERF	Frost Effects Research Facility
FID	Flame Ionization Detector
fps	Feet Per Second
GC/CON	Gas Chromatography with Electrolitic Conductivity Detection
GC	Gas Chromatograph
GPR	Ground Penetrating Radar
GRM	Generalized Reciprocal Method
HHRA	Human Health Risk Assessment
HI	Hazard Index
HQ	Hazard Quotient
IRDMIS	Installation Restoration Data Management Information System
LOAEL	Lowest Observed Adverse Effect Level
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MS	Mass Spectrometer
msl	Mean Sea Level
NAPL	Non-Aqueous Phase Liquid
NERI	Northeast Research Institute Inc.
NHDES	New Hampshire Department of Environmental Services
NIOSH	National Institute for Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
NOAEL	No Observed Adverse Effect Level
NWI	National Wetlands Inventory

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PAH	Polynuclear Aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
PCE	Tetrachloroethylene
PCL	Protective Contaminant Level
PID	Photoionization Detector
ppb	Parts Per Billion
ppm	Parts Per Million
QA/QC	Quality Assurance/Quality Control
QCP	Quality Control Plan
RfD	Reference Dose
RI	Remedial Investigation
RQD	Rock Quality Designation
SARA	Superfund Amendments and Reauthorization Act of 1986
SOP	Standard Operating Procedure
SP	Spontaneous Potential
SVOC	Semivolatile Organic Compound
TCA	Trichloroethane
TCE	Trichloroethylene
TCL	Target Compound List
TCLP	Toxicity Characteristic Leaching Procedure
TEPS	Total Environmental Program Support
TIC	Tentatively Identified Compound
TPH	Total Petroleum Hydrocarbons
USAEC	U.S. Army Environmental Center
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
USCS	Unified Soil Classification System
UST	Underground Storage Tank
UTM	Universal Transverse Mercator
VDOH	Vermont Department of Health
VOA	Volatile Organic Analysis
VOC	Volatile Organic Compound
VTDEC	Vermont Department of Environmental Conservation

CRREL:	RI Report
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Revision No.:	1
Date:	March 18, 1994

Executive Summary

On December 30, 1992, Arthur D. Little, Inc. was assigned Task 0003 under the Total Environmental Program Support Contract No. DAAA15-91-D-0016 with the U.S. Army Environmental Center (USAEC). The scope of this task was to perform a second phase of Remedial Investigation at the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, New Hampshire. CRREL's mission is to research and develop equipment and procedures for the Department of the Army for application in areas where extreme cold conditions have significant impacts on Army operations. CRREL is also involved in Department of Energy projects dealing with freezing for containerization of hazardous wastes along with other environmental projects.

The CRREL site is approximately 30 acres in size and contains several locations where past spills, disposal practices, and operations have contaminated soil and ground water. Past investigations have identified and prioritized Areas of Concern (AOCs) where contaminant sources may have been located. The purpose of a remedial investigation is to characterize the nature and extent of contaminants, and evaluate the risk posed to human health and the environment by the presence of the contaminants. This document provides a summary of the Phase I and Phase II RI data and draws conclusions as to the nature and extent of the contamination as well as the risk the contaminants pose to human health and the environment at CRREL.

The report is based on data collected during the field investigations performed between August 1991 and April 1992 by Ecology and Environment, and between May 1993 and October 1993 by Arthur D. Little. Field work included geophysical investigations, soil gas surveys, soil and sediment sampling, bedrock and overburden monitoring well installation, and sampling of ground water from the production wells, monitoring wells, and the Ice Well.

Results of the investigation indicate that two primary classes of contaminants, chlorinated hydrocarbons and petroleum hydrocarbons, are present at the site. They are present at the source areas as vapors trapped in the pores of the fine grained soils. Locally the contaminants are adsorbed onto soils. Contaminants are also present in the ground water moving below the site. The primary contaminant in the ground water, trichloroethylene (TCE) was found in all wells at the site, both overburden and bedrock, with the exception of one production well at the southern end of the site. Fractures in bedrock are infrequent. Some appear to be water bearing and are oriented toward the northwest and northeast. Petroleum hydrocarbons were detected primarily in soil samples, with low concentrations identified in samples from the monitoring wells.

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Evaluation of the health risk posed by the contaminants was performed by identifying potential scenarios through which on-site workers, children and visitors may come in contact with the contaminated materials. For all present and foreseeable future use scenarios no risk was identified. No ecological risks or impacts were identified. Recommendations for further actions at the site include evaluation of treatment at source areas, optimization of the on site production wells to control and treat contaminated ground water and regular monitoring of selected wells at and near the site.

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Revision No.:	1
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1.0 Introduction

This remedial investigation (RI) report, which also includes a baseline risk assessment, was prepared to address conditions at the Cold Regions Research and Engineering Laboratory (CRREL) located in Hanover, Grafton County, New Hampshire. It was prepared for the U.S. Army Environmental Center (USAEC), formerly known as the U.S. Army Toxic and Hazardous Materials Agency (USATHAMA), to fulfill the requirements of deliverable ELIN A004 under Task Order 0003 of the Total Environmental Program Support (TEPS) contract DAAA15-91-D-0016. This RI was developed in accordance with the following documents:

- *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988)
- *Geotechnical Requirements for Drilling, Monitor Wells, Data Acquisition, and Reports* (USATHAMA, 1987)
- *USATHAMA Quality Assurance Program* (USATHAMA, 1990)
- The latest U.S. Environmental Protection Agency (EPA) guidance, including updates from:
 - *The Superfund Amendments and Reauthorization Act (SARA) of 1986*
 - *The National Contingency Plan*, applicable requirements from the National Environmental Policy Act, Title I and II
 - *Interim Policy for the Management of Soils Contaminated from Spills/Releases of Virgin Petroleum Products*
 - *Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual*
 - *New Hampshire Code of Administrative Rules, ENV-Ws 410, Groundwater Protection Rules* (NHDES, February 1993)

This RI report is a synthesis of physical and chemical data collected during two distinct phases of investigation. Where appropriate or necessary, chemical and physical data from other sources were used to support conclusions made in this report. However, the basis for most of the conclusions in this report is data produced in accordance with USAEC standards.

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1.1 Purpose of Report

The purpose of this RI report is to determine if areas of suspected or documented releases (accidental or intentional) at CRREL present a threat to human health or the ecology within the area studied for this investigation. This report evaluates the completeness of the physical/chemical data base by determining the degree to which the conceptual site model can explain the distribution of contaminants.

This Phase II RI report contains the results of remedial field investigations conducted at CRREL. Invasive aspects of the field investigations to support this RI report were restricted to the confines of the CRREL property; however, the analysis of physical data and the sampling of selected media also occurred at nearby off-site locations. These locations included the Connecticut River, a monitoring well network located immediately across the river from CRREL in Vermont, and the Town of Hanover, New Hampshire municipal standby well. Therefore, while this RI report focuses on the site-specific attributes of CRREL, information from the surrounding area was also considered.

This study is an addendum to a previous RI conducted by Ecology and Environment, Inc., in 1992. The objectives of the Ecology and Environment Phase I RI were to obtain information regarding overburden, bedrock, and ground water conditions, assess the nature and extent of contamination in the various Areas of Concern (AOCs), and prioritize the AOCs. Appendix A includes analytical results from the previous RI. This report will assess and summarize the results of both RI studies.

1.2 Site Background

1.2.1 Site Description

CRREL is located on 30 acres of land, west of and adjacent to State Highway 10, 1.5 miles north of the Town of Hanover in Grafton County, New Hampshire (Figure 1-1). The Universal Transverse Mercator (UTM) coordinates for the center of CRREL are 4,844,545mN by 719,761mE. The site is roughly rectangular in shape and measures approximately 1,360 feet east to west, and 970 feet north to south at its maximum extent (Figure 1-2). CRREL consists of seven major buildings and other smaller support structures, including pump houses for five production wells and a ground water remediation building. A small storm water detention pond (100 feet by 50 feet) is located at the southwest corner of the site.

With the exception of the front lawn and front parking lot areas, CRREL is surrounded by a chain-link fence equipped with security gates. These gates remain open during normal working hours, but are secured at night, on weekends, and on holidays. The security gates utilize a card key system for operation. Student housing for Dartmouth College is located adjacent to the site on the north and south. Highway



PREPARED FOR

DATE: JAN. 19



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USAEC

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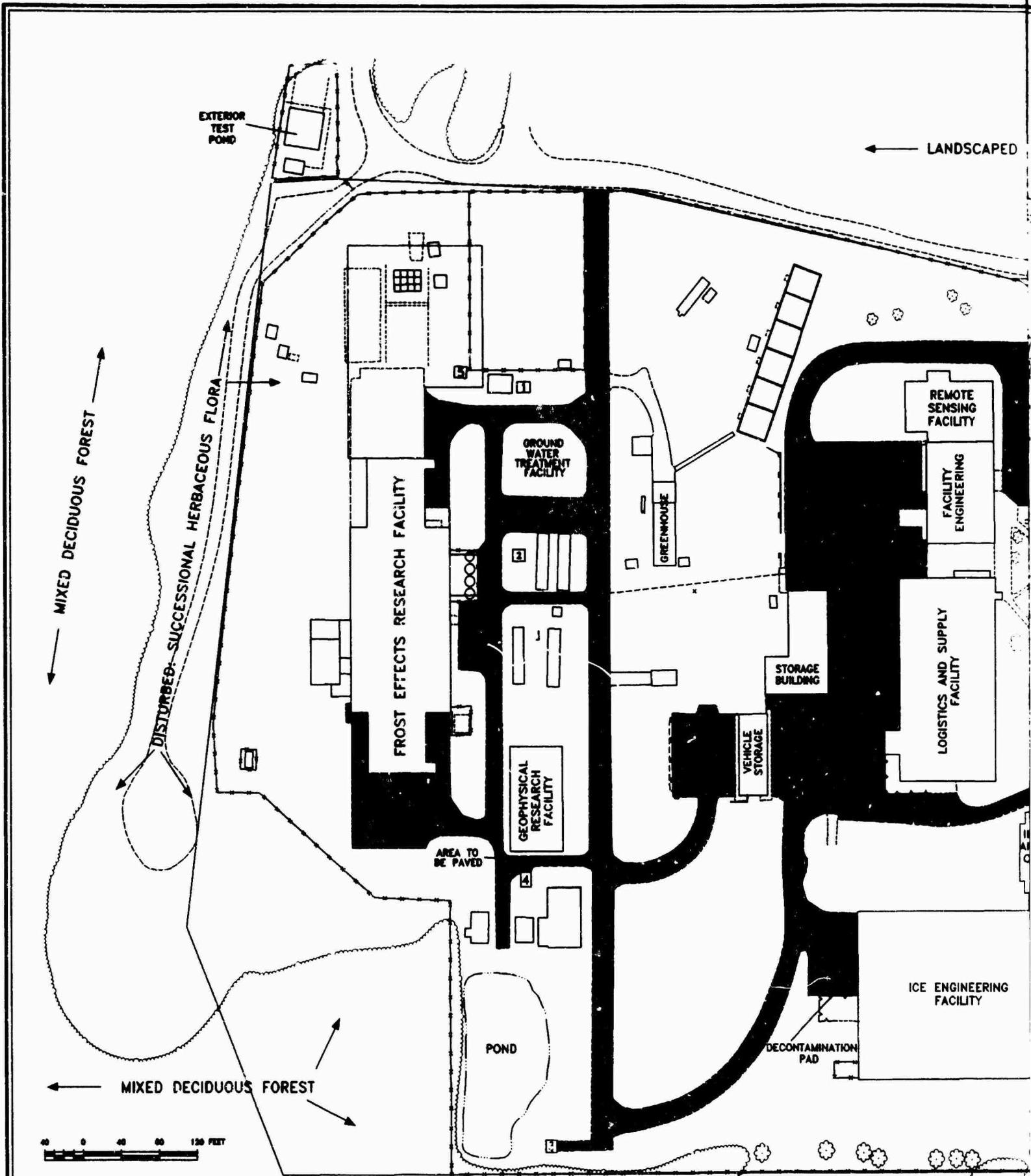
SOURCE: USGS, Hanover
NH-VT Topographic Quadrangle
1988

TITLE:

**FIGURE 1-1
SITE LOCATION MAP**

1 : 24,000

Arthur D Little



PREPARED FOR:

USAEC

DRAWN BY: (INITIALS)

MSB

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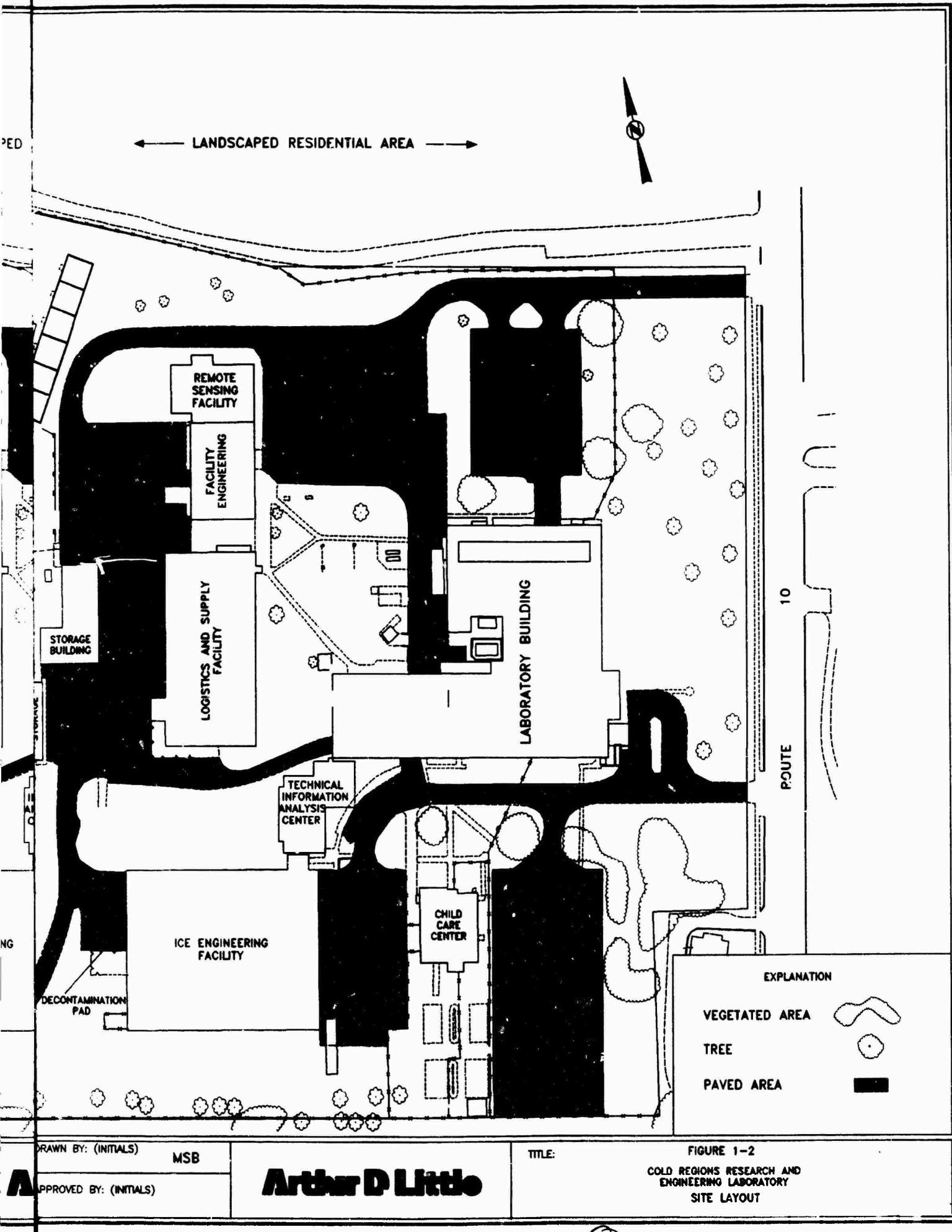
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10 forms the eastern boundary of the site, and the Connecticut River is located west of the CRREL property, separated from the site by a stump dump yard and a domestic refuse storage area.

1.2.2 Site History

CRREL was established on February 1, 1961 by the U.S. Army Corps of Engineers to combine the work of two predecessor organizations: the Snow, Ice, and Permafrost Research Establishment and the Arctic Construction and Frost Effects Laboratory. CRREL performs basic and applied research in snow, ice, and frozen ground. CRREL also provides the U.S. Department of the Army with practical engineering research to develop equipment and procedures for applications in cold regions.

In 1960, CRREL leased 19.2 acres of land from Dartmouth College for the purpose of constructing a research facility. Prior to CRREL construction, the land was used for agricultural purposes. Gravel was also mined on the western edge of the site. Construction started in June 1960, and the main laboratory building became fully operational in late 1963. Several buildings have been added over time. the Facility Engineering building (1968), the Logistics and Supply Facility (1976), the Main Laboratory Addition (1977), the Ice Engineering facility (1978), the Frost Effects Research Facility (1985), and the Child Care Center (1990). In 1982, 11.02 acres of additional land were purchased to accommodate the Frost Effects Research Facility (FERF), which is located along the western border of the original CRREL tract. The purchase expanded CRREL to its current size of 30.22 acres.

Recent construction also includes the new Sea Ice Pond, which was completed in the winter of 1992. The Remote Sensing Facility was completed in July 1993. The Technical Information Analysis Center was completed in November 1993. The permanent Ground Water Treatment Plant was completed in February 1994. The ATCO Building was recently demolished and removed from the property.

1.2.3 Previous Investigations

Prior to the initiation of this remedial investigation, several investigations related to suspected trichloroethylene (TCE) contamination at CRREL were conducted by various state and federal agencies, as well as CRREL personnel. Extensive sampling of surface water and ground water at CRREL, the Connecticut River, and on the west side of the river was conducted during most of these studies. In chronological order, the studies are:

- Response Action to TCE Explosion (July 1970)
- CRREL Site Investigations/Operation Sweetwater (November 1990)
- Monthly Monitoring of Residential and Municipal Wells in Vermont (December 1990)
- USAEC (formerly USATHAMA) Ground Water Sampling (March 1991)

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- Ground Water Investigation near Norwich, Vermont (1991)
- New Hampshire Department of Environmental Services (NHDES) Sampling (June 1991)
- Aerial Photographic Analysis (September 1991)

The significant aspects of each investigation are discussed below.

1.2.3.1 Response Action To TCE Explosion. On July 2, 1970, a tank located at AOC 1 exploded and subsequently released approximately 3,000 gallons of TCE that eventually entered the Connecticut River through CRREL's storm sewer system. Due to the amount of TCE released, scientists at CRREL speculated that TCE may have collected at the bottom of the river as an undissolved phase. On July 7, 1970, an internal investigation was initiated to determine the topography of the river basin and to determine the extent of TCE contamination in sediment in the vicinity of the CRREL storm sewer outfall and downstream locations. TCE was detected in the sediment, but no free-phase TCE was found within 0.5 miles downstream of the CRREL outfall.

River water samples were collected from July 14 through 30, 1970, from several locations. Two rounds of water sampling were performed at the Hanover Bridge, located 2 miles downstream of the CRREL outfall, and the Wilder Dam, located 4.4 miles downstream. The first round of samples was collected on July 14 and the second round of samples was collected on July 17. TCE was detected in the samples collected at the Wilder Dam at concentrations of 22 µg/L and 7 µg/L, for the first and second rounds, for the first and second rounds, respectively. TCE was detected in the samples collected at the Hanover Bridge at concentrations of 20 µg/L and 16 µg/L, respectively. River water was also sampled on July 17 at locations 1 and 5 miles upstream of the CRREL outfall. TCE was detected in the sample collected 1 mile upstream (7 µg/L), but was not detected in the sample collected 5 miles upstream.

Additional river water samples were collected as far as 30 miles upstream during the week of July 30. TCE concentrations in these samples ranged between 10 and 20 µg/L. Based on these results, CRREL personnel concluded that upstream sources of TCE likely exist and therefore, the release of TCE from the July 2 explosion did not raise the concentration of TCE in the Connecticut River significantly above background levels (Faran, undated).

1.2.3.2 CRREL Site Investigations/Operation Sweetwater. Ground water samples were first collected from CRREL on November 15 and 16, 1990. Ground water was sampled from production wells CECRL01, CECRL02, CECRL03, and CECRL04; and the Hanover supply well. Analysis for volatile organic compounds (VOCs) indicated that wells CECRL01, CECRL02, and CECRL04 contained elevated levels

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of TCE. No contamination was detected in well CECRL03 or the Hanover supply well.

On December 14, 1990, CRREL personnel directed the sampling of 7 residential wells located across from CRREL on the Vermont side of the Connecticut River. TCE was detected in the Peacock and Goodrich residential wells. The results of this investigation prompted CRREL to initiate Operation Sweetwater, which used CRREL's in-house capabilities to test the water supplies of all concerned citizens in the vicinity of CRREL.

In addition to Operation Sweetwater, CRREL sampled the five production wells, the refrigeration reservoir, and the outfall catch basin on a weekly basis from the time contamination was first detected. These results were submitted to EPA Region I and the NHDES. In addition, CRREL performed weekly sampling at three stations on the Connecticut River (the CRREL outfall, 100 feet upstream from the outfall, and 100 feet downstream from the outfall) since the discovery of TCE, and also sampled the Goodrich and Peacock residential wells while they remained active.

A total of 43 residential wells were sampled in New Hampshire and Vermont. Only the Peacock and Goodrich wells, located directly across the Connecticut River from CRREL, contained elevated levels of TCE. Of the three sampling stations on the Connecticut River, TCE was detected at the outfall and downstream stations 100 percent and 50 percent of the time, respectively. TCE was not detected at the upstream station.

In addition to environmental sampling, CRREL personnel have published several reports on the history of TCE use and handling at CRREL (Faran, undated), the results of CRREL's site investigation and analysis for TCE (Perry et al., 1991), and the geology and hydrogeology at CRREL (Gatto and Shoop, 1991).

1.2.3.3 Monthly Monitoring of Residential and Municipal Wells in Vermont.

Beginning on December 21, 1990, the Vermont Department of Health (VDOH) conducted monthly ground water sampling of 13 residential wells and the Town of Norwich municipal supply well. These wells are located on the west side of the Connecticut River in the state of Vermont. The VDOH analyzes these samples for VOCs at its laboratories following EPA Method 524.2.

TCE and cis 1,2-dichloroethene are consistently detected in the Peacock and Goodrich residential wells, located directly across the river from CRREL. In October 1992, TCE was discovered for the first time in the Britton well. It has been detected in three out of five sampling events, at levels at or below 10 ppb. No VOC contamination has been documented in the other wells. Low levels of trans 1,2-dichloroethene have also been detected in the Goodrich well.

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In response to these findings, all three residences have been connected to the Town of Norwich municipal supply. Samples are no longer collected at these locations, however, VDOH is presently considering converting these domestic supply wells to monitoring wells.

1.2.3.4 USAEC Ground Water Sampling. On March 19, 1991, CRREL personnel collected water samples from the storm sewer outfall, the five production wells (CECRL01 to CECRL05), the Ice Well (CECRL06), and the Peacock and Goodrich residential wells. The samples were sent to a USAEC-performance demonstrated laboratory (Arthur D. Little, Inc.) for organic (VOC) and inorganic (metals) analysis. These data have been assimilated into tables in Section 4.0 of this report.

TCE and tetrachloroethene (PCE) were the most commonly occurring VOCs. TCE was detected at the CRREL outfall at a concentration of 236 µg/L. TCE at a concentration of 360 µg/L was detected from the same sample using the GC/CON analytical method UG05. TCE was detected in all of the CRREL production wells except CECRL03. TCE concentrations in these wells ranged from 5.3 µg/L at CECRL04 to 800 µg/L at CECRL01. PCE was also detected at well CECRL02. TCE and PCE were detected at the Ice Well at concentrations of 36,000 µg/L and 200 µg/L, respectively. PCE was found in the Ice Well at a concentration of 1,700 µg/L by using the GC/CON analytical method UG05. TCE was detected at the Peacock and Goodrich residential wells at concentrations of 27 µg/L and 17 µg/L, respectively.

1.2.3.5 Ground Water Investigation Near Norwich, Vermont. As a result of the TCE contamination detected in the Peacock and Goodrich residential wells, the Vermont Department of Environmental Conservation (VTDEC) retained Wehran Engineering Corporation of Burlington, Vermont, to conduct a ground water investigation in the town of Norwich, Vermont. The investigation was initiated in early 1991, and involved the design of a ground water monitoring network to assess the hydrology, contaminant distribution, and the possibility of local sources of TCE on the west side of the Connecticut River. At the request of VTDEC, a bedrock aquifer investigation was performed in late Spring 1993 by the Johnson Company, Inc., at the Peacock, Goodrich, and Britton private bedrock water supply wells.

The Wehran investigation included the installation of five wells screened in the overburden (1S, 1D, 2, 4, and 5) and one well screened in the top 10 feet of bedrock (1B). Monitoring wells 1S, 1D, and 1B were installed in the immediate vicinity of the Goodrich well. Monitoring well 2 was installed 300 feet north of the Goodrich well. Monitoring well 4 was installed 300 feet south of the Peacock well. Monitoring well 5 was installed on the Vermont side of the river, approximately 3.2 miles south of CRREL. The Norwich Fire District well (designated well 6), which is screened in the same esker sand that underlies CRREL, was also used in the study. On April 23,

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1991, ground water samples were collected from these wells and analyzed for VOCs using EPA Method 8240. No VOCs were present above method detection in any of the overburden or shallow bedrock wells.

The Wehran report concluded that:

- The absence of VOC contamination in the overburden and shallow bedrock wells near the Peacock and Goodrich wells indicates that the source of contamination in the deep bedrock is not in the immediate vicinity of these residential wells.
- The TCE in the Peacock and Goodrich wells does not pose a significant threat to local town water supplies on the Vermont side of the Connecticut River.
- The ground water flow in the overburden appears to be generally horizontal and directed east toward the Connecticut River.
- Hydrogeologic data obtained about the overburden indicate that CRREL has not been shown to be a direct source of contamination in Vermont. However, the potential exists for contamination of wells on the Vermont side of the river from the historical releases at CRREL if there was a significant vertical downward movement of chlorinated solvents into bedrock.
- Migration of contaminants, from CRREL, through bedrock is possible, especially if bedrock fractures are oriented in an east-west direction.

Since the completion of this investigation, ground water sampling of these monitoring wells has been conducted on a quarterly basis by the Vermont Department of Environmental Conservation. No contamination has been detected during this testing (Young, 1992).

A bedrock aquifer investigation was conducted by the Johnson Company, Inc. to evaluate bedrock hydrogeologic conditions. The investigation included evaluation of ground water flow in the bedrock aquifer; determination of potential sources of TCE contamination found in the three wells (Goodrich, Peacock, and Britton), and identification of other water supply wells at risk of contamination.

A 72-hour pumping test was performed at the Goodrich well to determine if the three contaminated wells are in hydraulic communication one another. Other investigative methods used in this study included geophysical logging, mapping bedrock aquifer hydraulic heads, and mapping fracture traces.

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The Johnson Company report (1992) concluded that:

- Two separate ground water regimes in the bedrock aquifer were identified and the Connecticut River is most likely a principal hydraulic control for the bedrock aquifer in Norwich.
- No definitive source or migration pathways could be determined for TCE contamination as a result of this investigation. It was speculated that the Connecticut River and river bottom sediments and/or CRREL could be the potential source or sources.
- The Goodrich, Peacock, and Britton wells are hydraulically corrected, and the Connecticut River is the principle hydraulic control for the bedrock aquifer.
- Ten wells in the valley aquifer bedrock regime, including the Goodrich, Peacock, and Britton wells, were identified to be at some risk from TCE contamination. Wells identified as being at risk also included the Pinello well to the north of the Peacock well, and the Lewis, Sacks, and James Forcier wells south of the Goodrich well.

1.2.3.6 New Hampshire Department of Environmental Services Sampling. As a result of the TCE contamination identified at CRREL, NHDES conducted water sampling at five locations at and near CRREL on June 4, 1991. The NHDES laboratories analyzed these samples for VOCs, using EPA Method 624. The analyses yielded the following results:

Location	TCE Concentration (µg/L)
Refrigeration Reservoir (near Ice Well)	1,700
Outfall Catch Basin (near exterior test pond)	510
Connecticut River (50 feet upstream of outfall)	Non-Detect
Connecticut River (at outfall)	98
Connecticut River (50 feet downstream of outfall)	6.8

Since the time that these samples were collected, CRREL has redesigned its industrial water supply and storm water discharge system to the Connecticut River by constructing a ground water treatment system to remove VOCs. This system treats the water from CRREL production wells CECRL01, CECRL02, CECRL04, and CECRL05 by first pumping the water through a sand filtration system to remove

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metals and then distributing the water through two air strippers so that VOCs can be removed. The air effluent is treated through exposure to a carbon filtration unit. Once the water has been treated, it is contained in a reservoir until it is needed by the facility for the refrigeration system. After passing through the system, it is discharged to the Connecticut River.

1.2.3.7 Aerial Photographic Analysis. In September 1991, the Environmental Photographic Interpretation Center (EPIC) conducted an imagery analysis of CRREL through an interagency agreement between EPA and USAEC. The objective of the study was to interpret aerial photographs of the region taken between the years 1942 and 1982. The analysis focused on activities and features within CRREL that may have resulted in ground water contamination, but also covered the area within a 2-mile radius of CRREL.

Several major features were identified from the photographic analysis:

- An auto junkyard located approximately 1.7 miles northwest of CRREL. This site was first identified in 1955.
- Three quarries first identified on 1942 and 1956 photographs.
- A probable disposal area, first identified in 1970, located approximately 1.5 miles downstream of CRREL on the west side of the Connecticut River.
- An open storage area, first identified in 1956 photographs, located on the current property of the Goodrich residence.

1.3 Report Organization

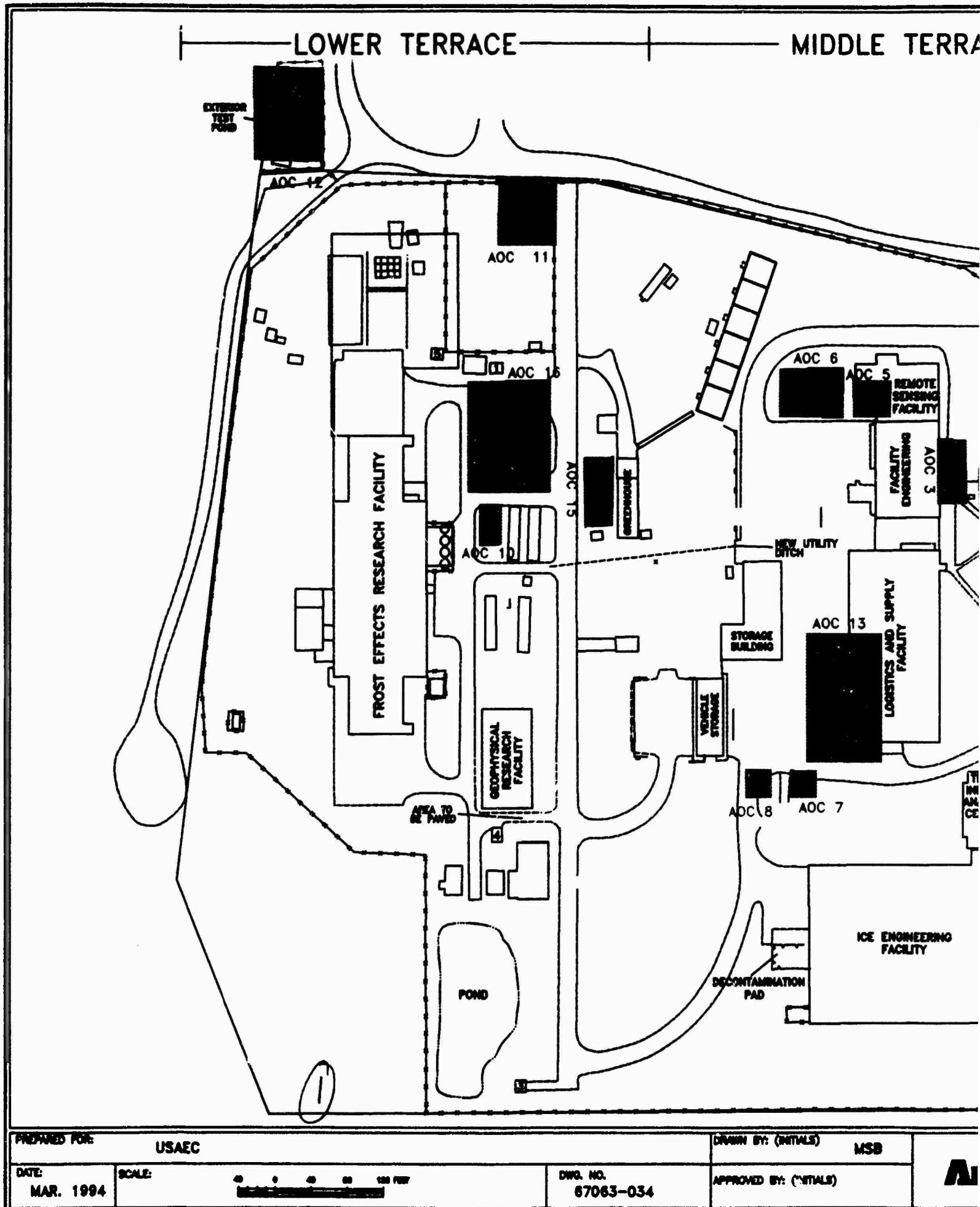
This report conforms to the suggested presentation format specified for RI reports in *Guidance for Consulting Remedial Investigations and Feasibility Studies* under EPA (1988). Section 1.0 describes the purpose of the RI report and the general site background. Section 2.0 defines the scope of the study area investigation. The first subsection (2.1) identifies specific AOCs defined prior to this investigation. The remaining subsections (2.2 through 2.6.4.1.2) describe the investigative methods used to study the physical and chemical features at each AOC. Section 3.0 presents the results of the physical characterization of CRREL and vicinity, based on literature search and/or the field investigation. This section emphasizes the development of a conceptual model to explain the distribution of site-related contaminants. Section 4.0 presents the nature and extent of chemical contamination of potentially affected soil, sediment, surface water, and ground water within the limits of the study area. Section 5.0 describes the contaminant fate and transport for chemicals detected at CRREL and vicinity within the framework of the conceptual model developed in Section 3.0.

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Section 6.0 includes the results of a human health risk assessment and an ecological impact assessment. Section 7.0 presents a summary of Sections 4.0 to 6.0, and conclusions regarding the completeness of the chemical and physical data for determining remedial alternatives, and potential remedial alternatives, if warranted by the risk assessment. Section 8.0 contains references for the report.

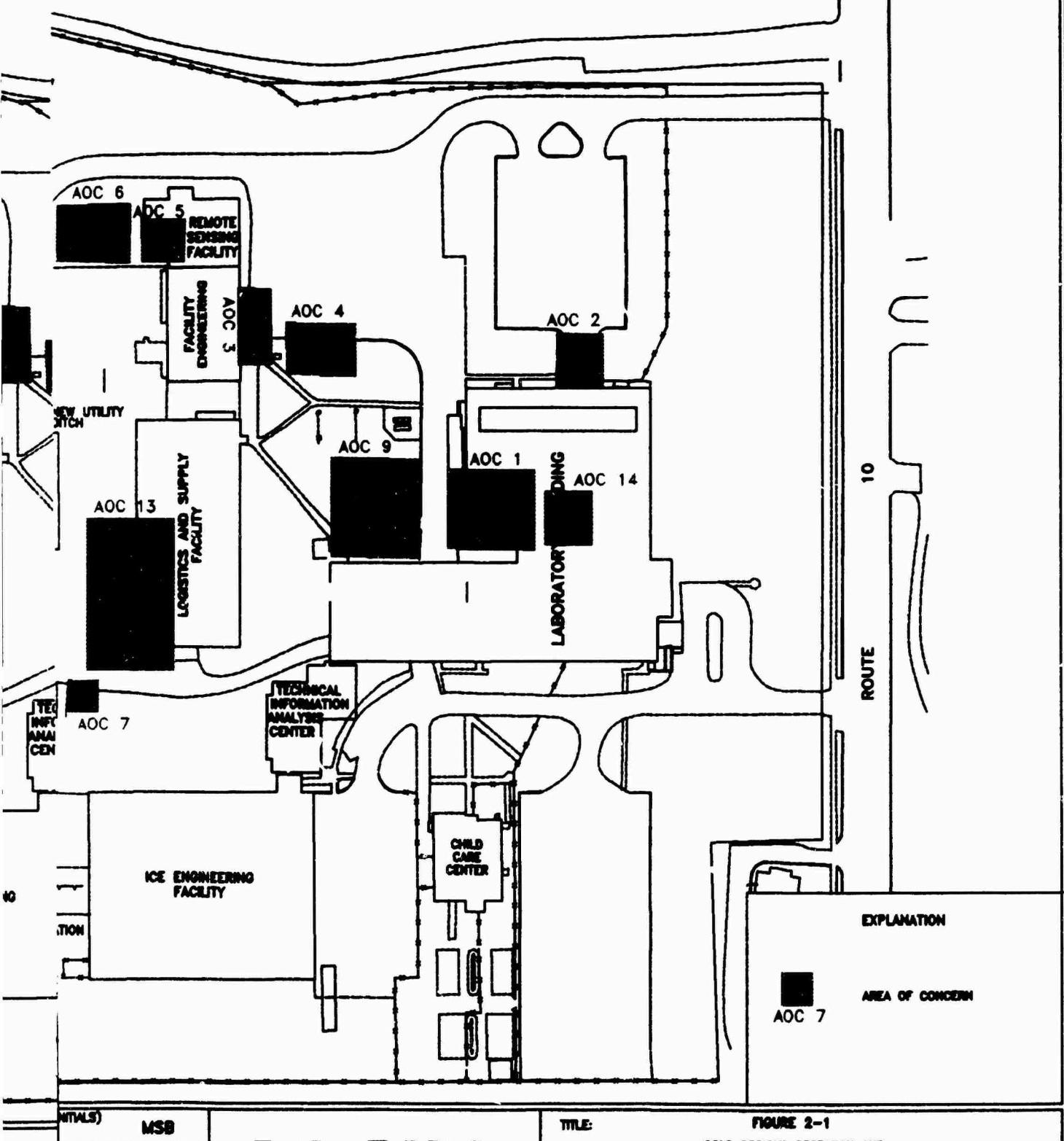
Table 2-1: CRRREL Remedial Investigation Field Activities - Phase I and II

AOC Location	Geologic Investigations				Soil Investigations				Ground Water Investigation			
	Surface Geophysics	Borehole Geophysics	Oriented Bedrock Coring	Overburden Geologic Logging	Sample Collection	Surface Soil	Subsurface Soil	Soil Vapor Monitoring Wells	Monitoring Well Installation	Ground Water Sample Collection	Well Testing	Water Level Measurements
AOC 1	x	x	x	x	x	x	x	x	x	x	x	x
AOC 2	x	x	x	x	x	x	x	x	x	x	x	x
AOC 3	x				x	x	x	x	x	x	x	x
AOC 4		x			x	x	x	x	x	x	x	x
AOC 5			x			x	x	x	x	x	x	x
AOC 6			x			x	x	x	x	x	x	x
AOC 7					x	x	x	x	x	x	x	x
AOC 8					x	x	x	x	x	x	x	x
AOC 9					x	x	x	x	x	x	x	x
AOC 10					x	x	x	x	x	x	x	x
AOC 11					x	x	x	x	x	x	x	x
AOC 12					x	x	x	x	x	x	x	x
AOC 13					x	x	x	x	x	x	x	x
AOC 14					x	x	x	x	x	x	x	x
AOC 15					x	x	x	x	x	x	x	x
AOC 16					x	x	x	x	x	x	x	x
Northern Boundary Child Care Center CRRREL Pond CRRREL Site (General)					x	x	x	x	x	x	x	x
Background Area I Background Area II Hanover Supply Well Connecticut River					x	x	x	x	x	x	x	x



RRA - MIDDLE TERRACE

UPPER TERRACE



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that contained either TCE, No. 2 fuel oil, or gasoline. The characteristics of each UST are briefly summarized in Table 2-2. Other AOCs at CRREL include storage areas, ponds, disposal areas, and a test structure known as the Ice Well. This section provides a brief description of each AOC.

2.1.1 AOC 1: Former TCE Storage Area

AOC 1 is located adjacent to the northwest corner of the Laboratory Building. It currently contains two aboveground storage tanks (ASTs): a 15,000-gallon tank installed in 1989 containing fuel oil and a 10,000-gallon tank installed in 1970 containing glycol and water. AOC 1 formerly contained an aboveground 10,000-gallon TCE tank, which exploded on July 2, 1970. The explosion resulted in the release of approximately 3,000 gallons of TCE to the pavement and nearby unpaved area to the west of AOC 1.

2.1.2 AOC 2: Former TCE and Fuel Oil UST Area

AOC 2 is located along the northern side of the Laboratory Building. The site formerly contained two USTs: a 10,000-gallon tank containing TCE and a 12,000-gallon tank containing fuel oil. The TCE tank was removed in 1972 and replaced by a 10,000-gallon fuel oil tank. The 10,000-gallon and 12,000-gallon fuel oil tanks were removed in 1989. A TCE odor was noticed during both the 1972 and 1989 excavations.

2.1.3 AOC 3: Facility Engineering's Former Fuel Oil UST Area

AOC 3 is located adjacent to the east side of the Facility Engineering Building. It formerly contained a fuel oil tank that was installed in 1968 and removed in 1989 after it failed two tightness tests. Upon removal, minor surface corrosion and a small hole were noted.

2.1.4 AOC 4: Facility Engineering's Current Fuel Oil UST Area

AOC 4 is located between the Facility Engineering Building and the temporary TCE Treatment Facility. It contains an active 6,000-gallon fuel oil UST that was installed in 1989. There have been no known releases from this tank. A 3,000-gallon fuel oil UST, which was installed in 1975 and removed in 1989, was also located at AOC 4. There were no known releases from this tank.

2.1.5 AOC 5: Diesel Fuel and Gasoline ASTs

AOC 5 is located on the northwest side of the Facility Engineering Building. This is the location of two 500-gallon ASTs containing diesel fuel and gasoline. There were no known releases from these tanks. This AOC is located within the footprint of the recently constructed Remote Sensing Facility.

Table 2-2: Underground Storage Tanks at CRREL

Location	Installation Date	Removal Date	Capacity Gallons	Construction Material	Release Detection	Corrosion Protection	Contents	Remarks
AOC 2	1960	1989	12,000	Steel	Manual Tank Gauging	None	No. 5 Fuel Oil No. 2 Fuel Oil	Contradictory removal/closure information.
AOC 2	1973	1989	10,000	Steel	Manual Tank Gauging	None	No. 2 Fuel Oil	Replaced tank. TCE odor at removal.
AOC 2	1960	1972	10,000	Steel	Manual Tank Gauging	None	TCE	Evidence of leakage. TCE odor at removal.
AOC 3	1968	1989	3,000	Steel	Manual Tank Gauging	None	No. 2 Fuel Oil	Failed tightness test on 1-24-89 and 2-1-89. Hole in tank contaminated clay with gravel for backfill.
AOC 4	1975	1989	3,000	Steel	Manual Tank Gauging	None	No. 2 Fuel Oil	Passed tightness test on 1-24-89
AOC 4	1989	-	6,000	Steel	Interstitial Monitoring with Automatic Inventory Monitoring	Double Steel Wall Cathodic	No. 2 Fuel Oil	Replaced tank above.
AOC 6	1968	1989	2,000	Steel	Manual Tank Gauging	None	Gasoline	Failed tightness test 1-24-89. Piping system leaked.
AOC 6	1968	1989	2,000	Steel	Manual Tank Gauging	None	Gasoline	Failed tightness test 1-24-89. Piping system leaked.
AOC 7	1974	1993	2,000	Steel	Manual Tank Gauging	None	No. 2 Fuel Oil	Passed tightness test 1-24-89/ Removed 10-07-93
AOC 15	1973	1986	2,000	Steel	Manual Tank Gauging	None	No. 2 Fuel Oil	Approximately 80 cubic gallons of soil removed Known release of 7+ barrels of oil.

Notes:

- indicates that the tank has not been removed

Source: Ecology and Environment (October 1992)

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2.1.6 AOC 6: Former Gasoline UST Area

AOC 6 is located approximately 50 feet west of the Remote Sensing Facility. It was the location of two former USTs, each with a 2,000-gallon capacity and used for the storage of gasoline. These tanks failed tightness tests and were removed in 1989. Failure of the tightness tests was attributed to the piping system.

2.1.7 AOC 7: Fuel Oil UST

AOC 7 is located midway between the western side of the Ice Engineering Facility and the Logistics and Supply Facility. It is the site of an operational 2,000-gallon fuel oil UST that was installed in 1974. This tank was certified as tight during testing on January 24, 1989. However, a leakage rate of 0.05 gallons per hour was attributed to piping. The tests indicate a leakage rate of 0.0018 gallons per hour from the tank itself.

2.1.8 AOC 8: Waste Oil AST

AOC 8 is located approximately 25 feet west of AOC 7. It is the site of an operational 500-gallon waste oil AST installed in 1990. There were no known releases from this tank.

2.1.9 AOC 9: Ice Well

AOC 9 is the location of the Ice Well (CECRL06), a cased boring fitted with a refrigeration coil for freezing water in the boring. It is 3 feet in diameter and approximately 200 feet deep. The Ice Well was formerly used for testing ice drilling technologies and was not constructed or used for injection or withdrawal of fluids from the ground. TCE was used in refrigeration lines and drilling fluid mixtures. This area may also contain TCE-contaminated soils resulting from the 1970 explosion of the former TCE tank in AOC 1. The refrigeration system for the Ice Well is no longer in operation, however, liquids and ice still exist within this well. AOC 9 is approximately 100 feet west of AOC 1.

2.1.10 AOC 10: Former Open Storage Area

AOC 10 is located at the current location of production well CECRL02. It is the former site of a open storage area that was used for the storage of containerized wastes, including TCE, from 1965 to 1974.

2.1.11 AOC 11: Concrete Storage Pad Area

AOC 11 is located at the northern boundary of CRREL on the lower terrace. The concrete storage pad was built in 1974, and used for the storage of containerized waste, including TCE.

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2.1.12 AOC 12: Exterior Test Pond Area

AOC 12 is located immediately north of the northwest border of the site. The exterior test pond was used for sea ice experimentation. The pond is fed by water from the CRREL storm sewer system. There were no known releases from experimental activities at this location.

2.1.13 AOC 13: Former Gravel Pad

AOC 13 is located between the Logistics and Supply Facility and the Storage Building. This was the location of a former gravel pad used for the disposal of spent TCE. The site is currently covered by a parking lot and road. A portion of the Logistics and Supply Facility footprint covers the site.

2.1.14 AOC 14: Main Laboratory Machine Room

AOC 14 is located within the Main Laboratory Building. TCE spills have been noted in this area.

2.1.15 AOC 15: Former Greenhouse Fuel Oil UST Area

AOC 15 is located adjacent to the west side of the Greenhouse Building. It was the location of a former 2,000-gallon fuel oil UST. The tank was installed in 1973 and removed in 1986 after leakage was observed. A total of seven barrels of leaked fuel oil were recovered during the excavation in 1986.

2.1.16 AOC 16: Former Open Storage Area

AOC 16 is located approximately 70 feet north of AOC 10. Like AOC 10, the site was used for the storage of containerized wastes, including TCE, until 1974. Visual observations of leakage were reported in this area. The site was covered with fill during the construction of the Frost Effects Research Facility (FERF).

2.2 Geologic Investigation

Geologic investigations of CRREL were performed to characterize subsurface physical features that are ultimately useful in developing a conceptual site model and interpreting chemical fate and transport (Section 5.0). Four categories of geologic investigations were conducted at various AOCs at CRREL:

- *Surface Geophysical Surveys* are a non-intrusive means to define selected subsurface characteristics such as buried stream channels and pronounced lithologic contacts.
- *Borehole Geophysical Surveys* were conducted to identify water-bearing fractures at four bedrock boreholes using a variety of tests that measure the physical properties of the bedrock and ground water in the borehole.

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- *Oriented Bedrock Coring* was performed at five bedrock boreholes to document the orientation of geologic structures and water-bearing fractures in the bedrock.
- *Overburden Geologic Logging* was conducted at all boreholes for the purpose of defining the stratigraphy both within and between AOCs.

2.2.1 Surface Geophysical Surveys

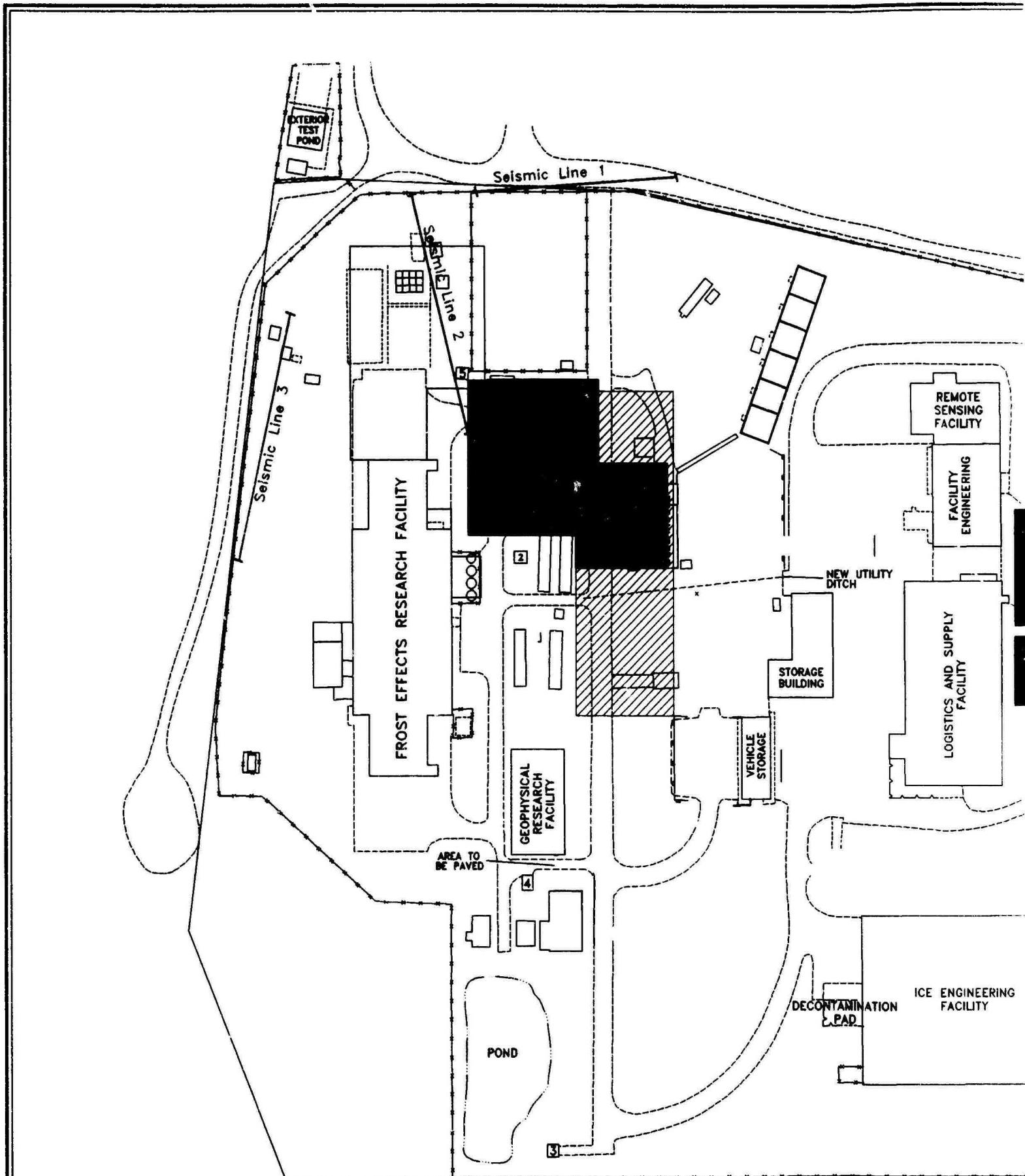
Surface geophysical surveys were conducted at selected areas of CRREL to define various subsurface features (Figure 2-2). Total Earth Field Magnetometry, Electromagnetic Ground Conductivity, and Ground Penetrating Radar (GPR) were conducted to help define certain shallow subsurface features up to a depth of approximately 20 feet. Seismic surveying also was conducted to define deeper geologic features, such as the bedrock surface. Surface geophysical surveys were conducted by Ecology and Environment, from August 26 through 28, 1991, during the Phase I field investigation and by Hager-Richter Geoscience, Inc., on June 9 and 10, 1993, under the direction of Arthur D. Little, during the Phase II field investigation. This report is included as Appendix C

Total Earth Field Magnetics

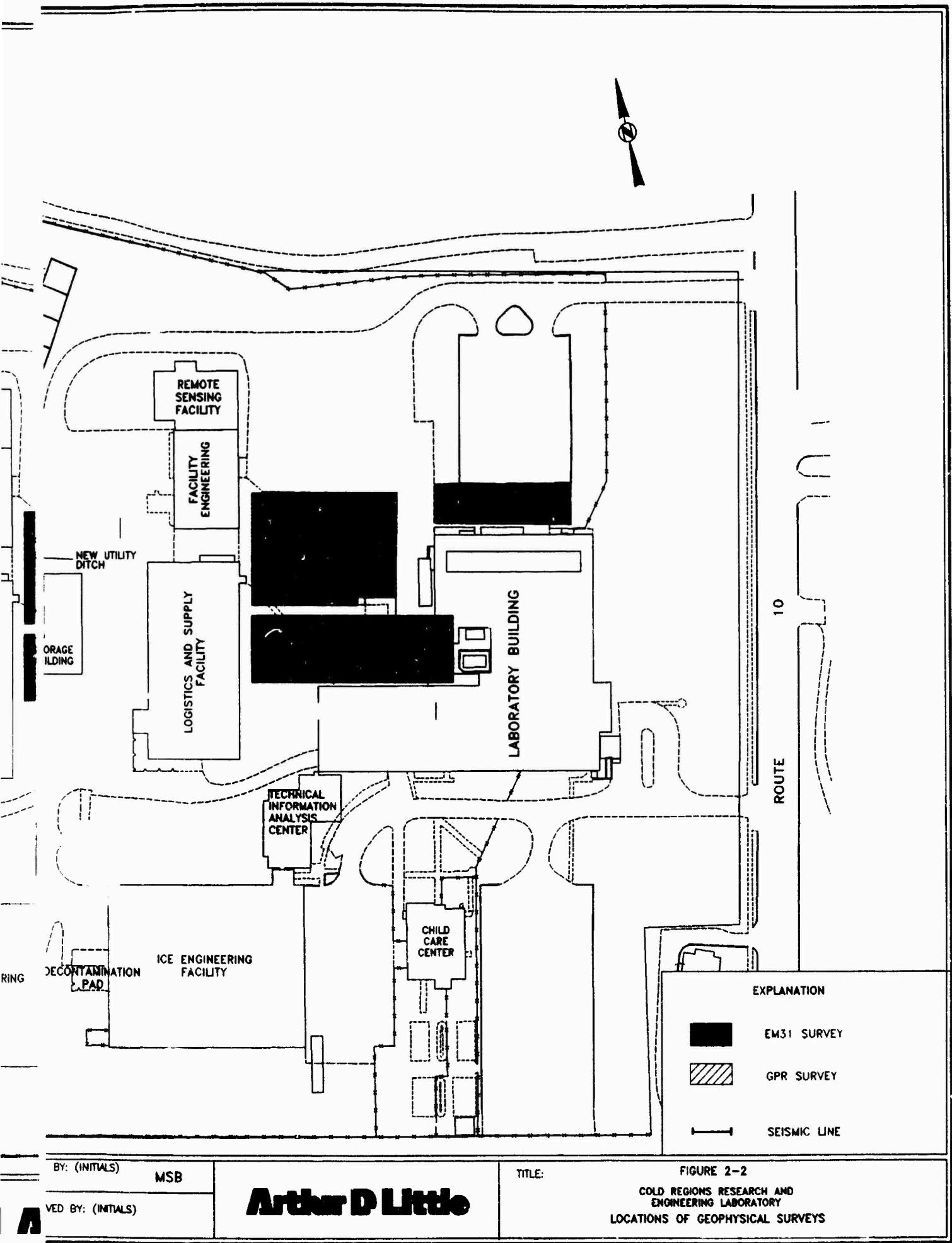
Total Earth Field Magnetic data were collected on variable sized grids at five sites at CRREL (Figure 2-2). Five grids (Nos. 1 to 5) were made by Ecology and Environment. Grids 1 to 4 were located in the vicinity of the Ice Well (AOC 9) and the Former TCE and Fuel Oil UST Area (AOC 2), but also included parts of AOCs 1, 3, and 4. Grid 5 was located over both Former Open Storage Areas (AOCs 10 and 16).

Total Earth Field Magnetic data were collected with an EG&G Geometrics G-856 proton magnetometer. This instrument measures the intensity of the earth's magnetic field approximately 9 feet above the terrain at each collection point. Subtle variations in this field may be caused by the natural distribution of iron oxides within the soil and rock. More significant changes in the magnetic field intensity are caused by the presence of buried objects composed of steel, iron, and other ferrous alloys. The response of the magnetometer is a function of the object's depth and mass.

All magnetic data were stored directly in the memory of the G-856 magnetometer. At each location, the G-856 stored the magnetic field strength, time, station number, and survey line number. The data were downloaded to an IBM compatible computer using the software package MAGPAC, Version 4.1.5 by EG&E Geometrics. MAGPAC corrects field data for diurnal drift and then converts those data to a form suitable for contouring. The corrected data were then plotted and contoured using the software package SURFER, Version 4.10 by Golden Software, Inc.



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Electromagnetic Ground Conductivity

Electromagnetic Ground Conductivity data were collected at six sites at CRREL. All data were collected on variable sized grids (Figure 2-2). Five grids (Nos. 1 to 5) were made by Ecology and Environment. Grids 1 to 4 were located in the vicinity of the Ice Well (AOC 9) and the Former TCE and Fuel Oil UST Area (AOC 2), but also included parts of AOCs 1, 3, and 4. Grid 5 was located over both Former Open Storage Areas (AOCs 10 and 16). One grid made by Hager-Richter Geoscience was located at the Former Greenhouse Fuel Oil UST Area (AOC 15).

The Electromagnetic Ground Conductivity investigations were performed using a Geonics EM31-DL terrain conductivity meter equipped with an Omni Data Logger Model 516GE-64-A (Ecology and Environment survey only). The EM31-DL has coils mounted with a fixed separation of 12 feet in a rigid boar. In normal operation, it is used with a vertical dipole, and the nominal depth sampled by the EM31-DL is about 18 feet. In the horizontal dipole mode, the nominal depth sampled is about 9 feet; however, in this position, the instrument is more sensitive to shallow features. Two components of the induced magnetic field measured by the EM31-DL are the quadrature-phase and in-phase components. The quadrature-phase component is a measure of the average terrain conductivity. The in-phase component is a sensitive indicator of the presence of conductive metal objects.

For grids 1 to 5, measurements were made at 10-foot intervals in the vertical and horizontal dipole positions. For the grid at AOC 15, quadrature phase and in-phase data were collected at 5-foot intervals. These data were then downloaded into an IBM compatible computer using the software package DAT31, Version 2.03, by Geonics, Ltd. DAT31 converts the field data into a suitable form for contouring. These adjusted data were then plotted and contoured using SURFER Version 4.10 software by Golden Software, Inc. Ground conductivity maps were generated for both the vertical and horizontal dipole modes.

Ground Penetrating Radar

GPR data were collected within a 320 foot by 120 foot grid located on the main access road on the lower terrace of CRREL (Figure 2-2). This area was once the site of an intermittent stream that was filled during construction on the lower terrace. The grid included all of AOC 15, and areas to the south where a soil gas survey (Section 2.4.3) was conducted. Fourteen parallel GPR traverses, generally spaced about 25 feet apart, comprise the grid. The total length of the survey was about 1,000 feet.

The GPR survey was conducted with a Model SIR-3:VDU-38 ground penetrating radar system. The system consists of an electronics unit, power supply, graphics recorder, color video display unit, and a transmitting/receiving antenna. The transmitting/receiving antenna is housed in a box that is moved across the surface. The antenna transmits high frequency electromagnetic signals to the subsurface and

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then detects, amplifies, and displays reflections of the signals in real time on a graphic recorder and a color video display unit. The data are also recorded on a tape recorder for post acquisition processing and interpretation. In general, the soil conditions were suitable for GPR penetration in excess of 10 feet.

Seismic Refraction

In the northwest corner of the site, seismic refraction was used to determine the depth of bedrock under the esker that passes beneath the AOC. Seismic refraction surveys were conducted along three transects, each 230 feet long (Figure 2-2). One seismic line (No. 1) was adjacent and parallel to the northern boundary of AOC 11, although it was off of the CRREL property. Two lines were oriented in a northerly direction, one subparallel to the western boundary of AOC 11 (No. 2) and one parallel to the western boundary of the site (No. 3).

Hager-Richter Geoscience used a 48-channel Bison Model 9048 Digital Instantaneous Floating Point Stacking Seismograph to conduct the survey. The Model 9048 is a microprocessor-controlled instrument that records data digitally and on paper seismographs. The seismograph was coupled to two 24-element seismic cables for a total of 48 geophones. The seismic source was a Bison EWG, a hydraulically operated accelerated weight drop. Five shot points were used for each 48-geophone spread. Shot points were located at the first, twelfth, and twenty-fourth (middle) geophones. Offset shots of up to 460 feet were made from the ends of the seismic lines. Elevations of the seismic lines and offset shotpoints were estimated from a topographic plan provided by CRREL.

The seismic data were analyzed using the Generalized Reciprocal Method (GRM) of seismic refraction interpretation. The GRM software used for data analysis was GREMIX by Interpex. The results are used to construct a velocity profile of the subsurface. Seismic velocities, which are a function of geologic material, are expressed in feet per second (fps).

2.2.2 Borehole Geophysical Survey

Borehole geophysical surveys were conducted from July 28 through July 30, 1993, at the bedrock boreholes on the CRREL site. The survey was conducted by Colog, Inc., of Golden, Colorado, under the supervision of an Arthur D. Little geologist. The objective of these surveys was to determine the physical properties of the bedrock, primarily the location, frequency, and size of water-bearing fractures. This information would assist in determining the most effective screened interval for the construction of the bedrock wells. Field copies of all geophysical logging runs were obtained for immediate use in determining fracture zone locations. The report produced for this investigation is included as Appendix D.

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Wells CECRL13, CECRL14, CECRL15, and CECRL18 were geophysically logged. Well CECRL16 was inaccessible due to drilling difficulties. The equipment used in the survey consisted of an Acoustic Televiwer (ATV) logger, a fluid resistivity and temperature probe, a formation resistivity probe, a caliper tool, and a natural gamma probe.

The ATV logger is an instrument that utilizes an acoustic wave transmitter and receiver, located together on a rotating sonde. As the sonde rotates and moves up the borehole, the acoustic signal is propagated through the borehole fluid and is reflected off the borehole wall. The attenuation of the acoustic signal is recorded and plotted, and then used to determine the competency of the rock. This transmitter/receiver is comprised of a transducer with a quartz crystal and is supported in its movement in the borehole by two centralizers, located on the upper and lower ends of the rod in which the electronic equipment is held. The results of the ATV logger are transmitted to a magnetic tape recording device and a printer, and yield visual evidence of fracture zones. Magnetic recorded data are used to perform advanced processing.

The fluid resistivity probe consists of a resistivity and temperature sensor mounted in a protective cage that measures the resistivity and temperature of the water in which it is immersed. As the probe is slowly lowered into the borehole, data are obtained and relayed to a digital recorder and graph printer.

The formation resistivity probe measures the electrical resistance of the adjacent borehole by employing a current transmitter and receiver. The transmitter and receiver are removed in distance from each other, thereby forcing the current to travel in a closed circle circuit through the formation. Three different transmitter/receiver spacings were used, however, only two are presented in the logs. The resistivity data are simultaneously recorded onto a digital recorder and graph logs and can assist in determining formation rock type and water content. It is normal procedure to employ a spontaneous potential (SP) log in conjunction with formation resistivity logs; however, due to influence from the 6-inch steel casing, its use was discontinued.

The caliper is composed of three steel arms connected to a lowering rod. These three arms are located on the bottom of the rod and are separated from each other by 120 degrees. As the caliper is raised up the borehole, the arms are in direct contact with the bedrock formation and thus physically graph the irregularities detected. The data are transferred electronically to a digital recorder and a printing device.

The natural gamma logger measures the naturally occurring gamma radiation in the borehole. It responds primarily to gamma rays from potassium (K^{40}), however, in igneous and metamorphic rocks there may be significant contributions from trace amounts of naturally occurring uranium and thorium. The tool consists of a detector tube, a pulse amplifier, a timer, and voltage regulator. This instrument measures

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gamma ray intensity in counts per second. As the logger is being raised from the bottom of the borehole, data are collected and transmitted to a digital recorder and graph printer.

Each well had the same borehole construction parameters. Extending from ground surface to 3 feet into bedrock, a 6-inch steel casing surrounded the 4-inch PVC riser pipe, with grout filling the void space. At this point, the 4-inch PVC pipe was surrounded only by bedrock, with the open borehole filled by a bentonite slurry seal located from 3 to 8 feet into bedrock and a Grade II sand pack extending to the bottom of the borehole. Detailed well construction diagrams can be found in Appendix E.

The following is a description of the general procedures for the logging of boreholes at CRREL:

- The bedrock wells were drilled and washed out with an Acker AD2 rig to ensure the removal of any detritus that may affect geophysical logging.
- The geophysical van was set up over the bedrock borehole. The water level was measured and PID readings taken in accordance with ADL SOP USA-4012.
- All instruments were calibrated.
- The borehole geophysics instruments were implemented in the following order: fluid resistivity and temperature probe, formation resistivity probe, caliper logger, gamma logger, and ATV logger. Each instrument was zeroed, insulated, and secured, and then lowered into the borehole. The respective parameters were logged while the instrument was raised to ground surface with the exception of the fluid resistivity and temperature probe which recorded data as it was being lowered into the borehole. The data were transferred electronically to an on-site data logger and graph printer. This procedure was repeated if the obtained data were incomplete or unclear. All instruments were decontaminated with a hand held sprayer immediately after removal from the borehole.

After preliminary surveys of CECRL13, CECRL14, CECRL15, and CECRL18, it was determined that silt influx to wells CECRL14, CECRL 15, and CECRL18 reduced the quality of the data. Silting of the wells resulted in the inability to lower the probes and loggers to the bottom of the boreholes, and thus the surveys did not yield complete information concerning fracture zones. Therefore, it was decided that the silted wells would be reamed and washed through mud rotary procedures. After borehole cleaning was completed, the geophysicists and geologists returned to the site and performed a second survey on the borehole, following the methodology outlined

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above. However due to time constraints, only the caliper and the ATV logger were used, as these instruments yielded the data most vital to the investigation.

For quality assurance checks of the instruments, repeat runs were completed at CECRL18 and CECRL15 for the ATV logger, caliper, formation resistivity probe, and the gamma logger.

2.2.3 Oriented Bedrock Coring

Oriented bedrock coring was performed prior to the construction of bedrock monitoring wells at CECRL13, CECRL14, CECRL15, CECRL16, and CECRL18. The coring was performed by Environmental Drilling, Inc., using the equipment and technical supervision of Christensen-Boyles Brothers, Inc. The coring was initiated on July 14 and was completed on July 23, 1993. At each borehole 25 feet of bedrock was cored. This was a sufficient depth to yield water-bearing fractures in the lower 10 feet of the borehole, while still providing adequate space to properly construct wells.

Oriented bedrock coring implements many of the same coring techniques used to obtain standard bedrock cores; however, an oriented core allows the hydrogeologist to define the fracture zones from which preferential migration pathways of ground water (and contaminants) can be interpreted. The coring performed at CRREL consisted of two primary steps. The first step was to core and describe the bedrock. The second step, which was performed after all of the cores were obtained, was to orient selected intervals of core (i.e., those that contained potential water-bearing fractures) with a goniometer.

Bedrock was cored using an NX coring bit, which produced cores approximately 2 inches in diameter and a 2.75-inch diameter borehole. The core barrel, which was 15.63 feet long, was capable of retrieving 5 feet of bedrock per run within the inner core barrel sleeve. The inner sleeve contained a mechanism for physically scribing three lines in the bedrock during the coring process. One of these lines, known as the master scribe line, was oriented with respect to a compass-camera assembly located in the upper 5 feet of the inner core barrel sleeve. During coring the orientation of the master scribe line was automatically recorded by photographing the compass at specific intervals. The following is a description of the step-by-step methodology for obtaining and describing one run (typically 5 feet) of oriented bedrock core:

- The technician prepared the compass-camera assembly for insertion into the core barrel. During this step, a timer on the camera was set to automatically photograph the compass at two minute intervals. The compass-camera assembly was prepared in a dark area, typically under a blanket in a vehicle near the rig.

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- The compass-camera assembly was set into the upper part of the inner core barrel sleeve and the entire inner sleeve was lowered through the coring rods until it locked into position at the base of the core barrel. The coring technician started a stopwatch when a core run began so that he could track exactly when photographing occurred. Although photographs of the compass were automatically taken every two minutes, vibrations caused by the spinning of the core barrel produced blurred photographs. Therefore, coring was stopped at three predetermined intervals within the run so that clear photographs of the compass could be made. Typically these intervals were at 0.5, 2.5, and 5.0 feet. An unavoidable feature of compass-driven oriented coring was that accurate data could not be collected for the upper 10 feet at any borehole because the 6-inch protective steel casing distorted the compass readings. Since the compass was set approximately 10 feet into the core barrel, 10 feet of bedrock was cored before the compass was beyond the influence of the steel casing.
- During the run, the geologist recorded the penetration rate in minutes/0.5 feet or minutes/1.0 feet, the pulldown pressure (psi), and any other information that may have reflected bedrock characteristics.
- At the completion of a run, the inner sleeve was removed along with the rock core and the film. In accordance with USAEC Geotechnical Requirements, the rock core was immediately placed into a core box so that the top of the run was at the left end of the box. The first run at each borehole was placed at the back (closest to hinges) of the box, with deeper runs progressively closer to the front of the box. A schematic diagram showing the layout of the runs in the core box was drawn on the inside lid of each box. Other information recorded on the outside and inside of the core box included the borehole (well) number, sampling date, contractor name (ADL), the specific runs in the box (e.g., runs 1 to 3), run intervals, and core box number (e.g., box 1 of 2).

Logging of the bedrock was performed on wetted samples in accordance with the USAEC specifications. Logging included the written description and photographic recording of each core run. The description of each run can be found in Appendix F. Particular attention was paid to the location and distribution of water-bearing fractures. The procedure for identifying water-bearing fractures, as opposed to annealed or mechanical fractures, was to document evidence of unusual amounts of weathering and/or the presence of rust to orange colored iron-precipitate staining. Annealed fractures, although not generally water-bearing, are those fractures that have been sealed by the precipitation of secondary minerals, typically quartz and calcite. Rock Quality Designation (RQD) values were calculated for each run, based on annealed and water-bearing fractures.

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After the completion of all bedrock logging, all of the suspected water-bearing fractures (except those in the upper 10 feet of the borehole) from each of the boreholes were oriented with a core goniometer. A brief description of the fracture orientation method and the core orientation data sheets are presented in Appendix F.

As a measure of quality control on the orientation data, the orientation of the dominant foliation was measured on the core from each run where water-bearing fractures were present. Based on local geologic mapping the dominant foliation is northeasterly and dips to the west. For an oriented water-bearing fracture to be accepted as accurate, the measured direction of the dominant foliation must have fallen in this range.

2.2.4 Overburden Geologic Logging

Overburden geologic logging was conducted as part of the subsurface soil investigation (Section 2.4.2) and monitoring well installation program (Section 2.5.1). All geologic logging was performed in accordance with the procedures described in *Geotechnical Requirements for Drilling, Monitor Wells, Data Acquisition, and Reports* (USATHAMA 1987) and Arthur D. Little SOPs USA-4002, *Standard Penetration Tests and Split Spoon Sampling*, and USA-4001, *Exploratory Boring Procedures*.

Geologic data were recorded in the field on soil boring logs. These logs are provided in Appendix G.

The procedure for sample collection and logging was as follows:

- A 2-inch diameter by 2-foot long split spoon was advanced 2 feet in front of the augers by repeated blows with a 140-pound hammer dropped 30 inches.
- When the split spoon was recovered from the borehole, the geologist measured the amount of sample recovery (in tenths of feet) and screened the sample for total volatile organic compounds with a Microtip Photoionization Detector (PID).
- The geologic description of the soil included the following elements: color, grain size distribution, sorting, moisture, compaction, and general stratigraphic features. The color of the soil was compared to standardized colors on the Munsell color chart. An estimate of the grain size distribution (e.g., fine to coarse), and sorting (e.g., poorly to well) was provided for the sand component of the sample. For the sand, silt, and clay components, volumetric percentages were estimated for the primary and secondary soil components (e.g., 20 percent coarse sand, 80 percent medium sand). The relative moisture content for all geologic material was divided into three categories: wet, moist, and dry. Wet sand contained free water in pore spaces, while wet silt and clay yielded beads of water when lightly

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tapped. Moist sand contained wet grains, but no interstitial water, while moist silt and clay yielded water only when compressed. The degree of compaction was estimated from the results of the standard penetration test for the sample interval. General stratigraphic features included descriptions of bedding, geologic contacts, and staining.

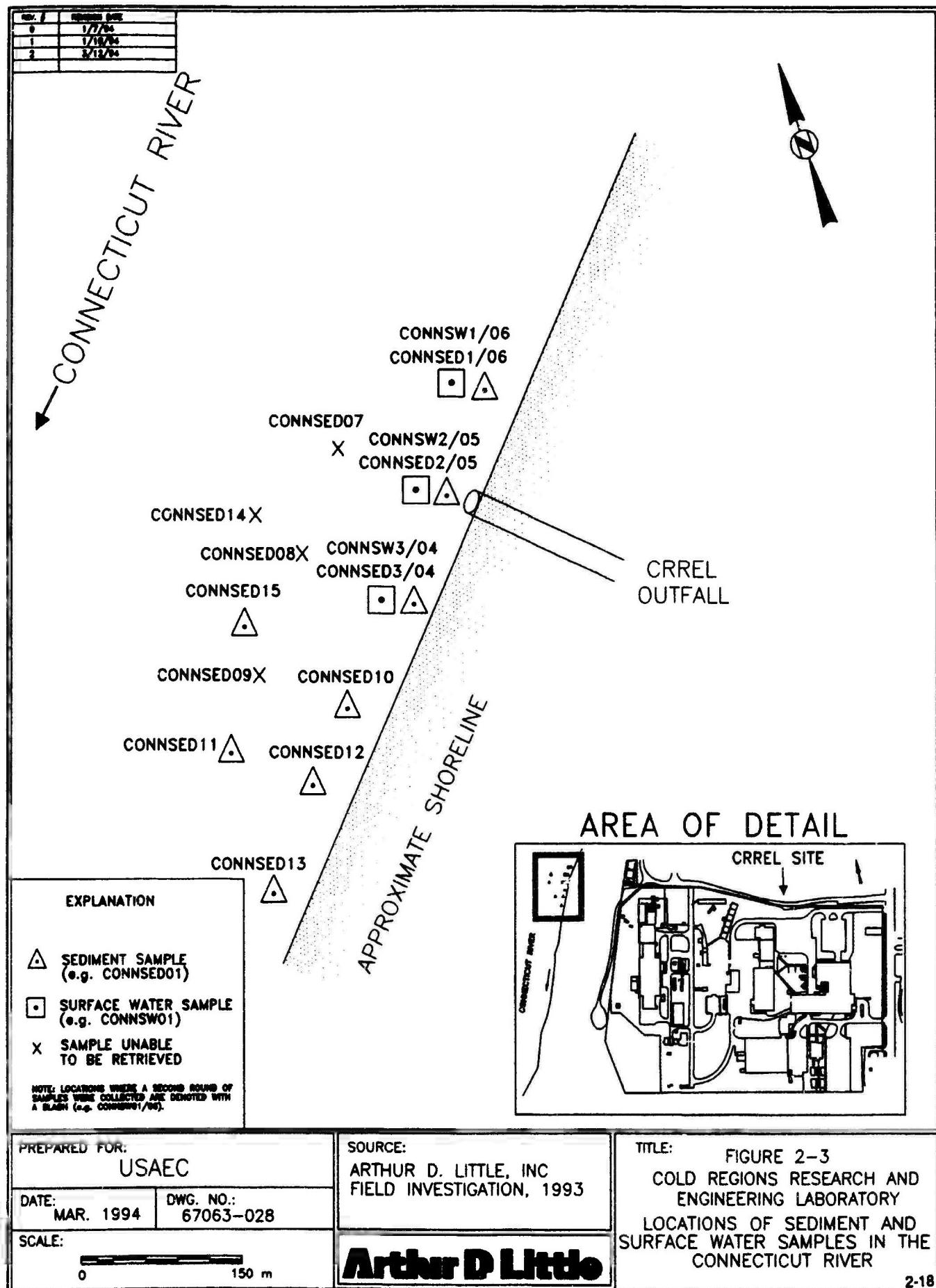
- The geologic classification of the soil was performed in accordance with the Unified Soil Classification System (USCS).
- Geologic samples from each interval were placed in one-half pint clear glass jars. Each jar contained the following information: boring designation, sample interval, date sampled, and the contractor's name. The samples were delivered to the CRREL Environmental Engineer for on-site storage.
- A total of 30 geologic samples were collected with a Shelby tube from CECRL07 through CECRL12, CECRL17, CECRL19, 2SB5, 2SB6, 9SB2, 13SB3, 13SB4, and 15SB2 for geotechnical analysis of particle size distribution and Atterberg limits.

In addition, the stratigraphy to top of bedrock was logged for CECRL17 and CECRL19. This logging occurred prior to the construction of the overburden wells in order to aid in the determination of stratigraphic cross sections and bedrock topography.

2.3 Sediment and Surface Water Investigation

Sediment and surface water samples were collected from the Connecticut River to determine sediment and surface water conditions in the vicinity of the CRREL outfall. Figure 2-3 shows the location of the sediment and surface water samples. Three rounds of sediment samples and two rounds of surface water samples were collected.

The first round of sediment sampling was conducted by Ecology and Environment on April 9, 1992. The second and third rounds were conducted by Arthur D. Little on June 24 and October 22, 1993, respectively. The first round consisted of three locations -- 100 feet upstream of the CRREL outfall (CONNSED1), at the CRREL outfall (CONNSED2), and 100 feet downstream of the CRREL outfall (CONNSED3). For the second round, 12 sediment sampling locations (CONNSED4 to CONNSED15) were selected. These samples encompassed an area that extended approximately 200 feet across the Connecticut River from the CRREL outfall to approximately 400 feet downstream of the CRREL outfall (see Figure 2-3). The thick gravel bed at the bottom of the river prevented sediment sampling at locations



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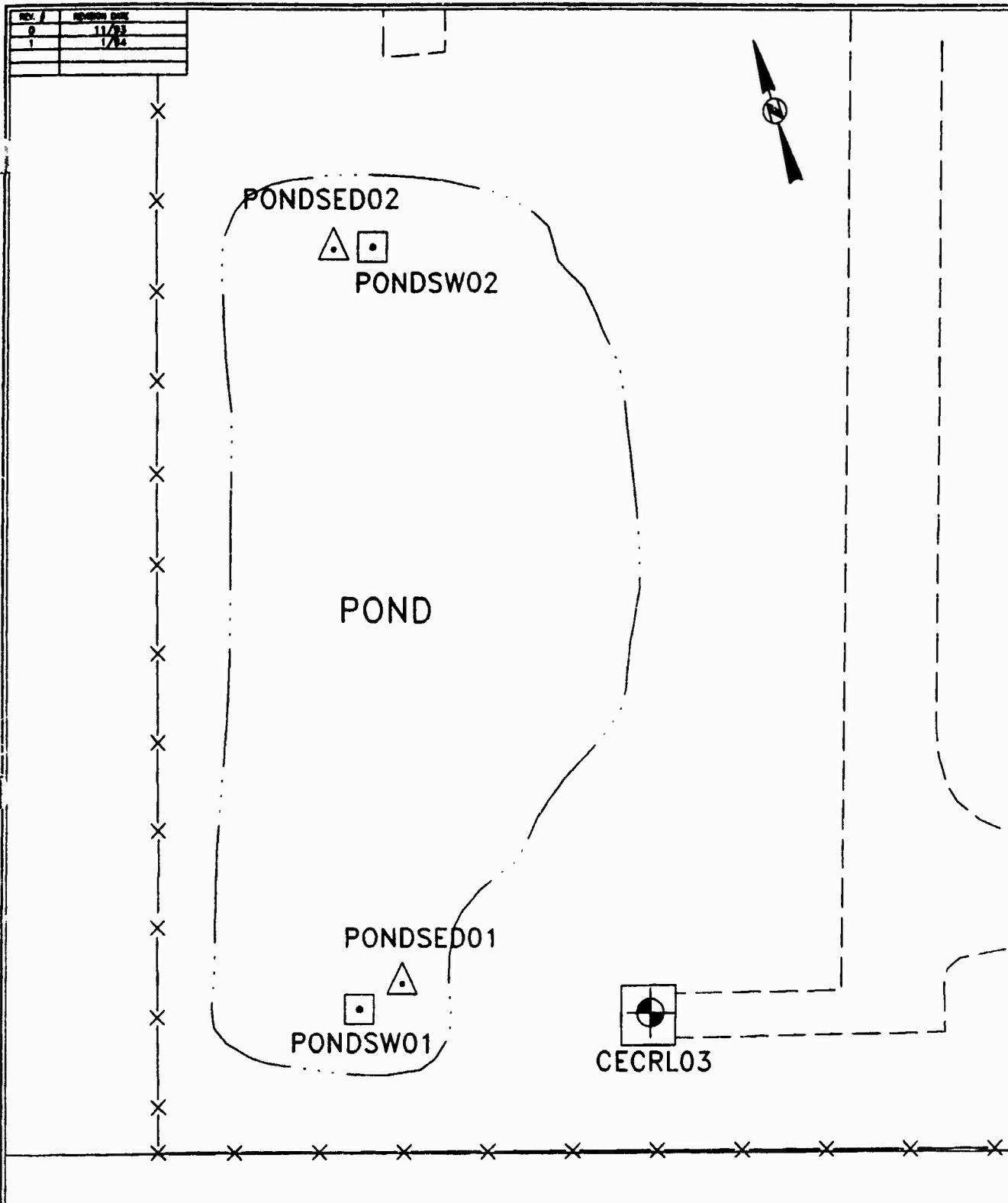
CONNSED7 to CONNSED9 and CONNSED14. The third round consisted of re-sampling sediment at seven locations where sediment was successfully sampled during the second round (e.g., CONNSED4 to CONNSED6 and CONNSED10 to CONNSED13). Sediment from CONNSED15 could not be collected during the third round because of a gravelly substrate.

The first round of surface water sampling was conducted by Ecology and Environment on April 9, 1992, in conjunction with the sediment sampling. The samples were collected from three locations -- 100 feet upstream of the outfall (CONNSW1), at the CRREL outfall (CONNSW2), and 100 feet downstream of the outfall (CONNSW3). The second round of sampling was performed by Arthur D. Little on June 24, 1993, during the second round of sediment sampling. This sampling round consisted of collecting three samples (CONNSW4, CONNSW5, and CONNSW6) from the surface water locations chosen in round one.

Sediment and surface water samples were collected at two locations in CRREL pond by Arthur D. Little on October 1, 1993. Figure 2-4 illustrates the sampling locations. Samples PONDSED01 and PONDSW01 were located at the southeast end of the pond, near production well CECRL03. Samples PONDSED02 and PONDSW02 were located at the northwest end of the pond.

Sampling points in the Connecticut River for rounds two and three were located by Hydro Data, Inc., of Chester, Connecticut. Sampling locations were approached from the downstream direction to minimize turbidity within the water column. Downstream locations were sampled before upstream locations. Where the water was greater than 4 feet deep, sediment samples were collected from a boat using a Ponar sampler. Where the water was less than 4 feet deep, hand augers were used to penetrate the gravelly sediment. A hand auger was used for sediment sampling in CRREL pond. All sediment samples were retrieved from the upper 1 foot of sediment. Surface water samples were collected from the upper 6 inches of the water column by direct submergence of jars into the water. Field measurements of pH, conductivity, and temperature were made using a Horiba U-10 meter at each location where surface water was sampled.

During the first round, sediment and surface water samples were analyzed for Target Compound List (TCL) organics and Total Petroleum Hydrocarbons (TPH). For rounds two and three, sediment samples were analyzed for VOCs, and surface water samples were analyzed for VOCs, benzene, toluene, ethylbenzene, and xylene (BTEX), and TPH. Sediment and surface water samples from CRREL pond were analyzed for VOCs, BTEX, and TPH. All sampling equipment was decontaminated according to the procedures described in Section 2.8.



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LEGEND

- SURFACE WATER LOCATION
- SEDIMENT LOCATION
- MONITORING WELL LOCATION

Arthur D Little

TITLE:

FIGURE 2-4
COLD REGIONS RESEARCH AND
ENGINEERING LABORATORY

LOCATIONS OF SEDIMENT AND SURFACE
WATER SAMPLES IN THE CRREL POND

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2.4 Soil Investigation

Soil investigations consisted of three main components: the surface soil investigation, the subsurface investigation, and the soil gas investigation. The surface soil investigation was implemented to provide exposure point data for a human health risk assessment (Section 6.0). The subsurface investigation was implemented to determine the lateral and vertical distribution of contaminants at specific AOCs. The subsurface investigation also provided information regarding the geology and hydrogeology of the overburden. The soil gas investigations were designed to assist in determining the location of the soil borings and overburden monitoring wells throughout the site. The soil gas investigation in Phase II was focused at AOC 15.

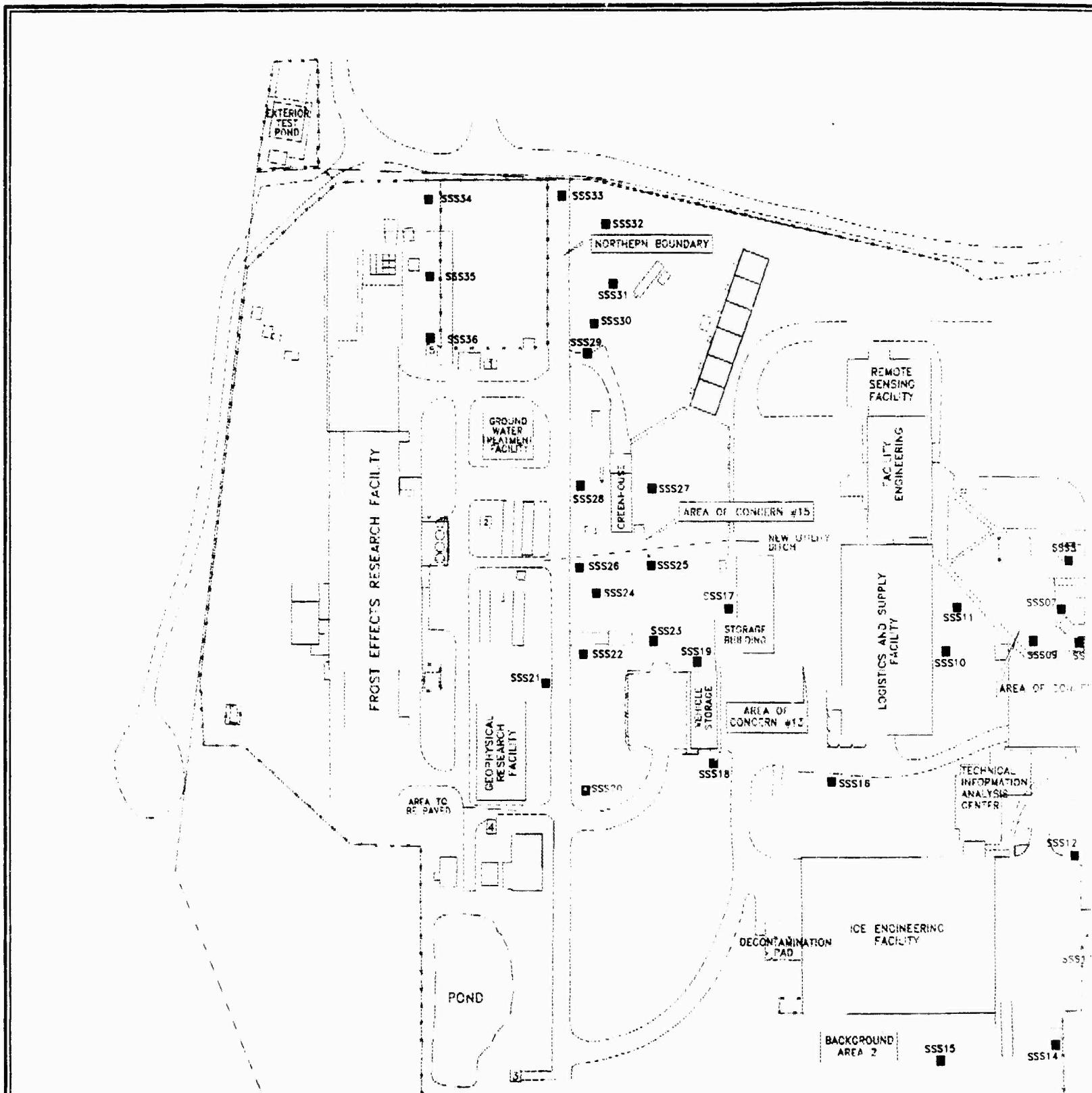
2.4.1 Surface Soil Investigation

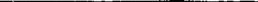
The surface soil investigation was performed at 37 locations (SSS01 to SSS37) between August 2 and August 4, 1993, with re-sampling of SSS37 on August 13 and August 20, 1993. Surface soil samples were collected throughout the site with focus on specific AOCs (AOCs 2, 9, 13, and 15), the Child Care Center, and background areas located between the AOCs, as shown in Figure 2-5. Samples were collected at locations where soil disturbance was minimal and as far away as possible from the effects of runoff from paved areas. Samples were analyzed for VOCs, BTEX, and TPH.

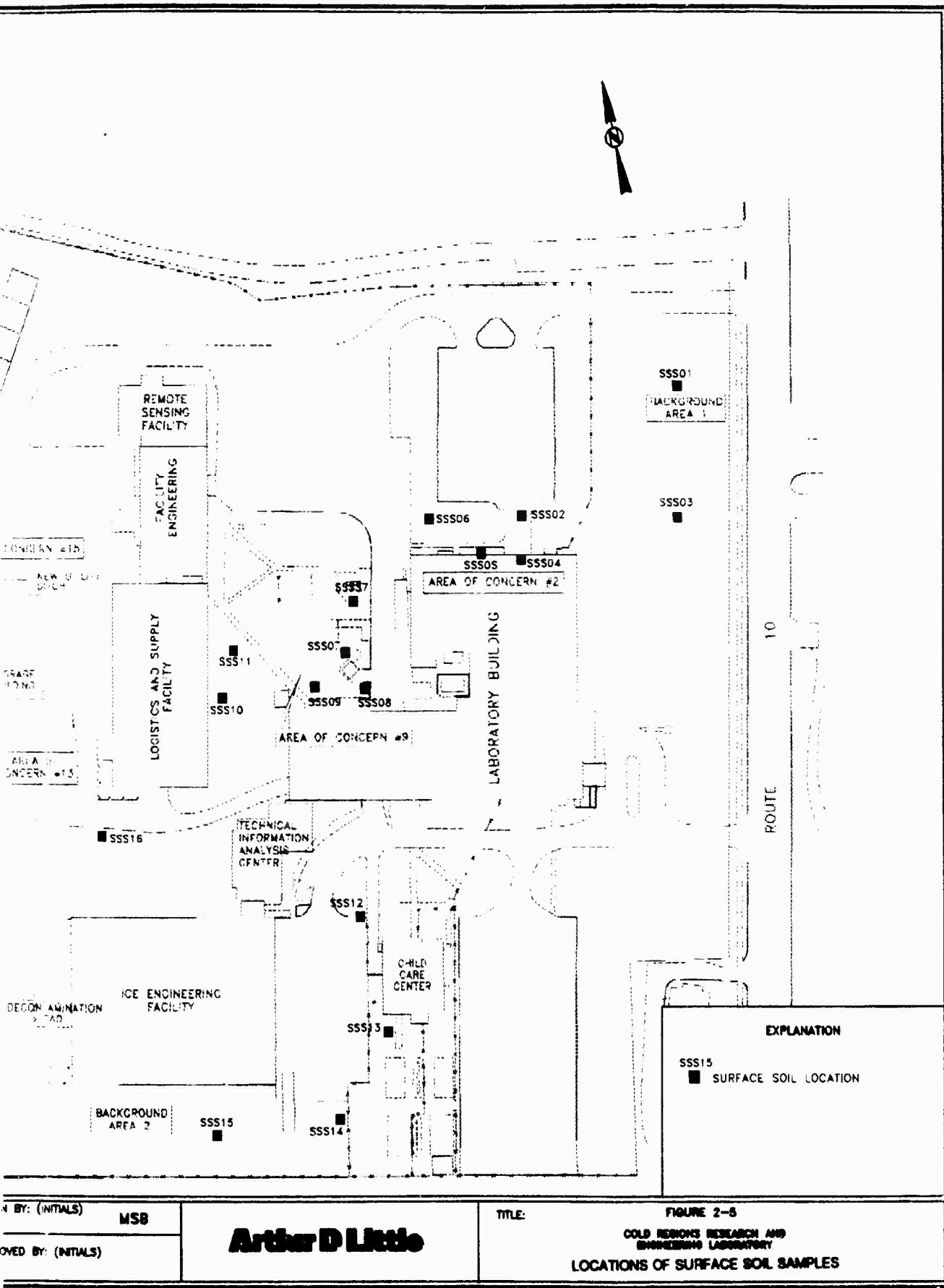
The samples were collected in accordance with the Arthur D. Little Quality Control Plan using the following procedure:

- A stainless steel hand auger, trowel, and bowl, along with all sampling containers, were transported to the site.
- All loose debris was removed with the trowel, and samples were taken at a depth of 0.5 to 1.0 feet below surface with the hand auger. Immediately after the auger was removed from the borehole, the soil was transferred into 4-ounce pre-labeled sampling vials and screened with a PID. Each label on the bottles contained the pertinent information about the surface boring (e.g., site ID, sample interval, date sampled, and contractor code).
- After the sampling was complete, the geologic characteristics of the soil were described according to ADL SOP 4014. The remaining soil was returned to the auger hole, and the top soil and grass to its original location.

The shallow soil sampling program was performed in accordance with the CRREL Phase II RI Work Plan, with three exceptions. First, after further investigation into the site layout by the Arthur D. Little risk assessment team, the decision was made to incorporate an additional surface soil sample (SSS37). This sample was located in a



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garden area adjacent to a fuel oil tank and a glycol and water tank at AOC 1. The second deviation from the Work Plan involved moving sampling locations SSS16 to SSS19 off of a paved roadway near AOC 13. These sample locations were moved to unpaved areas that most closely approximated the original site. The final deviation involved moving location SSS03, originally located in AOC 2, to Background Area 1.

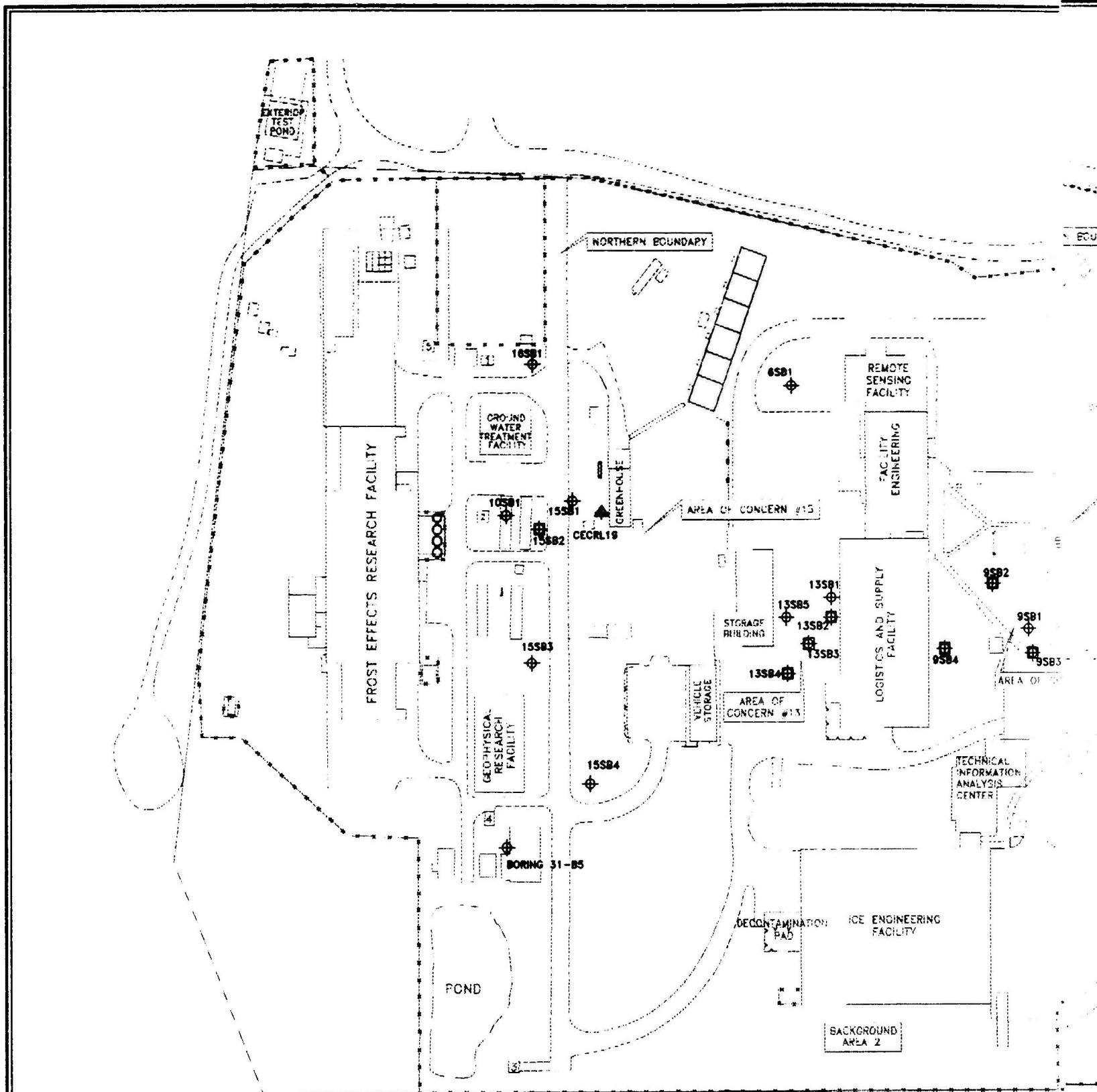
2.4.2 Subsurface Soil Investigation

The subsurface soil investigation was conducted at AOCs where historical data indicated a release or potential release of contaminants (AOCs 2, 6, 9, 10, 13, 15, and 16). The Phase I field investigation, which was performed from January 10 to January 20, 1992, determined if contamination existed at selected AOCs. The Phase II field investigation, which was conducted from July 7 to August 13, 1993, was designed to determine the lateral and vertical extent of contamination at these AOCs.

The locations of the soil borings are shown in Figure 2-6. Eight soil borings (2SB1, 2SB2, 6SB1, 9SB1, 10SB1, 13SB1, 15SB1, and 16SB1) were drilled during the Phase I field investigation using continuous soil sampling to depths between 10 and 55 feet bgs. Fifteen soil borings (2SB3, 2SB4, 2SB5, 2SB6, 9SB2, 9SB3, 9SB4, 13SB2, 13SB3, 13SB4, 13SB5, 15SB3, 15SB4, 15SB5, and CECRL19) were drilled during the Phase II investigation and were typically sampled at 5-foot intervals to depths ranging between 55 and 170 feet below ground surface (bgs). However, during the Phase II investigation, two boreholes in AOC 15 were continuously sampled at specific depths.

Appendix B shows the analytical program for the subsurface soil sampling program. Twenty-eight soil samples were collected for chemical analysis of VOC and TPH during the Phase I field investigation. Sixty-one soil samples were collected for chemical analysis of VOC, BTEX, and TPH during the Phase II investigation. Field QC samples were collected as described in Section 2.6.4.1.2.

Drilling was performed using 6 1/4-inch diameter (ID) hollow stem augers during the Phase I investigation, and both 6 1/4-inch and 4-inch diameter (ID) hollow stem augers during the Phase II field investigation. The sampling intervals and depths were site-specific, but were based on criteria described in the Work Plans (Ecology and Environment, 1991; Arthur D. Little, 1993). For the Phase I field investigation, continuous samples were collected to a minimum of 10 feet bgs, but continued until background concentrations of total VOC, as measured by a PID, were present. For the Phase II field investigation, samples were collected at 5-foot intervals to a depth of 50 feet bgs or until two consecutive samples indicated background concentrations of VOCs. However, to eliminate the possibility of cross contamination, all soil borings were terminated at a maximum depth of 10 feet above the water table, even



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0 5 10 15 20 25 30 FEET

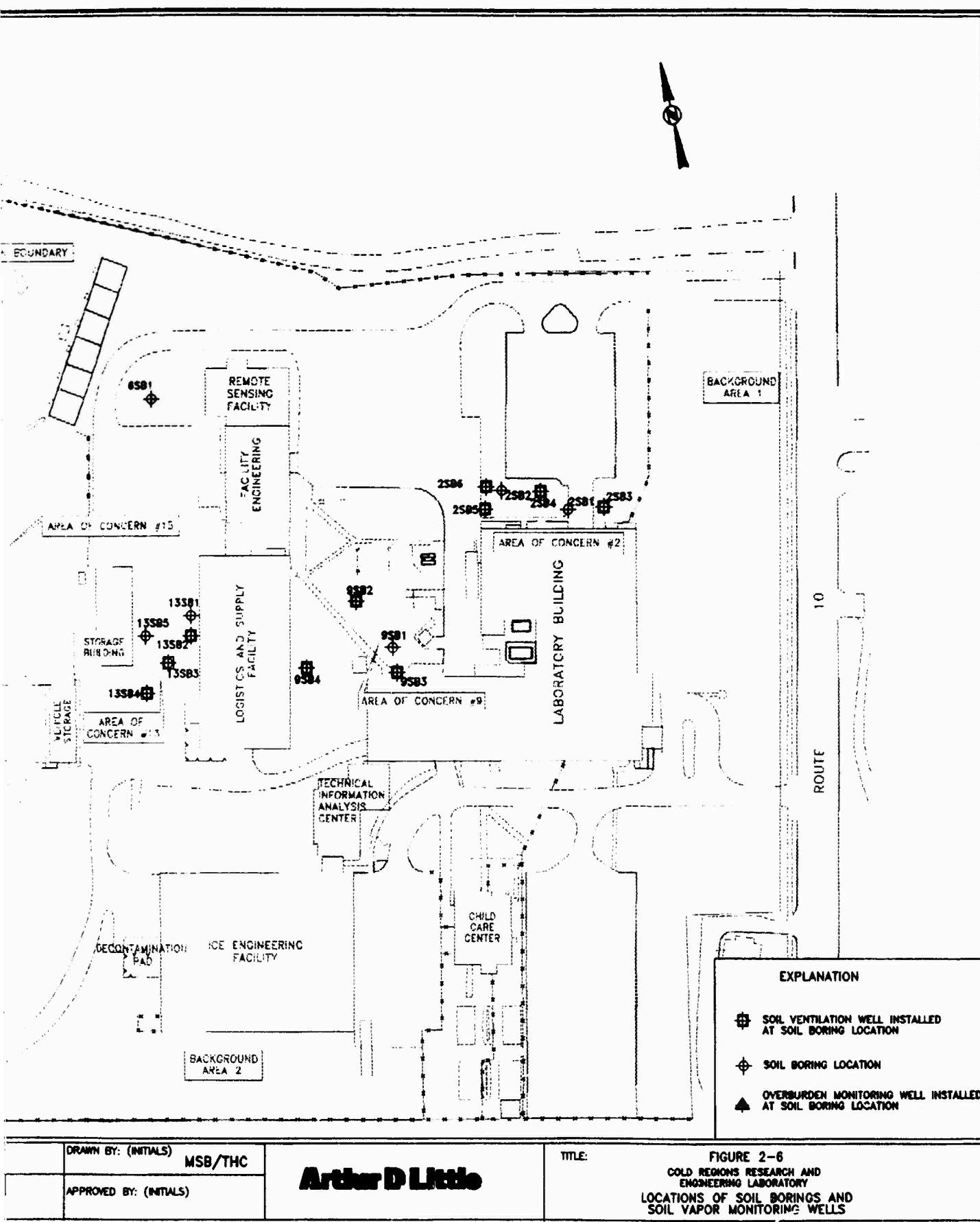
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when background concentrations had not yet been reached. Sample collection and geologic logging were conducted according to the procedures described in Section 2.2.4.

All chemical sampling was performed in accordance with USAEC guidelines as described in the Work Plans (Ecology and Environment, 1991; Arthur D. Little, 1993). Sampling during the Phase II investigation also followed ADL SOP USA-4002. The general procedure for chemical soil sampling was as follows:

- All decontaminated equipment needed for chemical soil sampling was set up at the site
- Immediately after the split spoon was opened, all chemical soil samples were collected in 4-ounce glass amber jars. Sample containers were filled as quickly as possible, with those for VOC analysis collected first, followed by a headspace screening sample, and then the TPH analysis sample. Generally, VOC soil samples were collected within one minute of opening the split spoon. With the exception of the headspace screening sample, all of the samples were immediately placed in an ice-filled cooler.
- Headspace screening analysis was performed on all soil samples, using a Microtip PID equipped with a 10.6 eV lamp and calibrated to 100 ppm with 100 ppm isobutylene. The following method was used. Headspace samples were placed in clear 8-ounce glass jars. After filling the jar half full of soil, the jar was covered with aluminum foil and gently agitated. After several minutes, the PID probe was inserted through the foil into the air above the sample and the highest screening value was recorded on the soil boring log.
- The selection of soil samples for chemical analysis at a boring were made with the assistance of headspace screening results. Typically samples for chemical analysis were collected at the shallowest and deepest intervals where contamination was detected with the PID. In addition samples for chemical analysis were also collected from the interval where the highest levels of contamination were indicated by the PID and from other intervals of unique geology to ensure a diverse selection of geologic material.
- At the completion of the chemical sampling, the boring was either abandoned with a cement grout or was used for a soil vapor monitoring well as described in Section 2.4.4.
- All investigative-derived waste was handled in accordance with the procedures described in Section 2.7.

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- All sampling instruments were decontaminated in accordance with the procedures described in Section 2.8.

Table 2-3 describes site-specific soil sampling conditions for each AOC.

2.4.3 Soil Gas Investigations

Two soil gas surveys were conducted at CRREL. These surveys were performed by Northeast Research Institute Inc. (NERI) of Farmington, Connecticut. The first survey was performed during the Phase I field investigation to determine if VOC contamination existed at the 16 AOCs, to identify any additional AOCs, and to aid in the selection of soil boring and monitoring well locations. The second survey was conducted at the beginning of the Phase II field investigation to identify potential migration pathways and aid in the location of soil borings and monitoring wells in the vicinity of AOC 15. Figure 2-7 shows the areas where soil gas surveys were conducted for the Phase II investigation.

Both surveys were performed in accordance with "Petrex® Environmental Soil Gas Protocol" and were previously submitted to USAEC as individual reports. The Petrex® method used by NERI provides a means by which trace quantities of gases from subsurface derived organic contaminants can be both detected and collected at the earth's surface. This technique is passive and integrative, thus eliminating any short-term variations and increasing the effectiveness with which it identifies VOCs. The gases are collected through samplers that consist of two collectors, each collector being a ferromagnetic wire coated with an activated carbon adsorbent and mounted in a screw top glass culture tube. When placed into shallow holes, these samplers can collect trace gases from the soil, vadose zone, and ground water.

The procedure for use of these samplers during both surveys was as follows:

- Adsorption collector wires were cleaned, packaged and checked prior to transportation to the site, according to NERI protocol.
- The sampler was placed open end down into a shallow hole, 14 to 18 inches deep.
- The hole was backfilled with an aluminum foil plug and the excavated soil. The location was marked with ribbon flagging and a numbered pin flag. To ensure that the locations would be well documented for retrieval, the site was drawn in a field notebook and plotted on a field map.
- After eighteen days, the samplers were retrieved by a NERI specialist who extracted the sampler by exposing the tube with a trowel and removing it with a pair of tongs.

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Table 2-3: Site-Specific Soil Sampling Conditions

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Location	Boring Number	Auger Size IN ID	Sampling Interval FT BGS	Total Depth FT BGS	Disposition
AOC 2	2SB1	6 1/4	9-11 15-17 24-26 44-46	46	Grouted to surface
AOC 2	2SB2	6 1/4	1-3 8-10	10.5	Grouted to surface
AOC 2	2SB3	6 1/4	20-22 25-27 30-32 35-37	67	Soil Ventilation Well installed
AOC 2	2SB4	4	14-16 44-46 94-96 119-121	121	Soil Ventilation Well installed
AOC 2	2SB5	4	20-22 25-27 30-32 35-37	120	Soil Ventilation Well installed
AOC 2	2SB6	6 1/4	14-16 35-37 45-47 60-62 65-67	120	Soil Ventilation Well installed
AOC 6	6SB1	6 1/4	1-3 8.5-10.5	10.5	Grouted to surface
AOC 9	9SB1	6 1/4	2-4 13-15** 17-19 53-55	55	Grouted to surface
AOC 9	9SB2	4	49-51 54-56 69-71 89-91	101	Soil Ventilation Well installed
AOC 9	9SB3	4	10-12 40-42 100-102 115-117	117	Soil Ventilation Well installed
AOC 9	9SB4	4	4-6 9-11 14-16 19-21	51	Soil Ventilation Well installed
AOC 10	10SB1	6 1/4	0-2 4-6 9-10	10	Grouted to surface

Notes:

- * Duplicate sample collected from this depth
- ** Sample analyzed for total petroleum hydrocarbons (TPH) only
- *** Due to drilling complications a new boring, 13SB4ALT, was drilled 6 feet northeast of 13SB4. This boring, with a stratigraphy and headspace comparable to 13SB4, was designated as the new location of the soil ventilation well.
- **** Mud rotary was implemented when the depth exceeded 120 feet below ground surface

IN ID Inches of the inner diameter of hollow stem augers

FT BGS feet below ground surface

Table 2-3: Site-Specific Soil Sampling Conditions (continued)

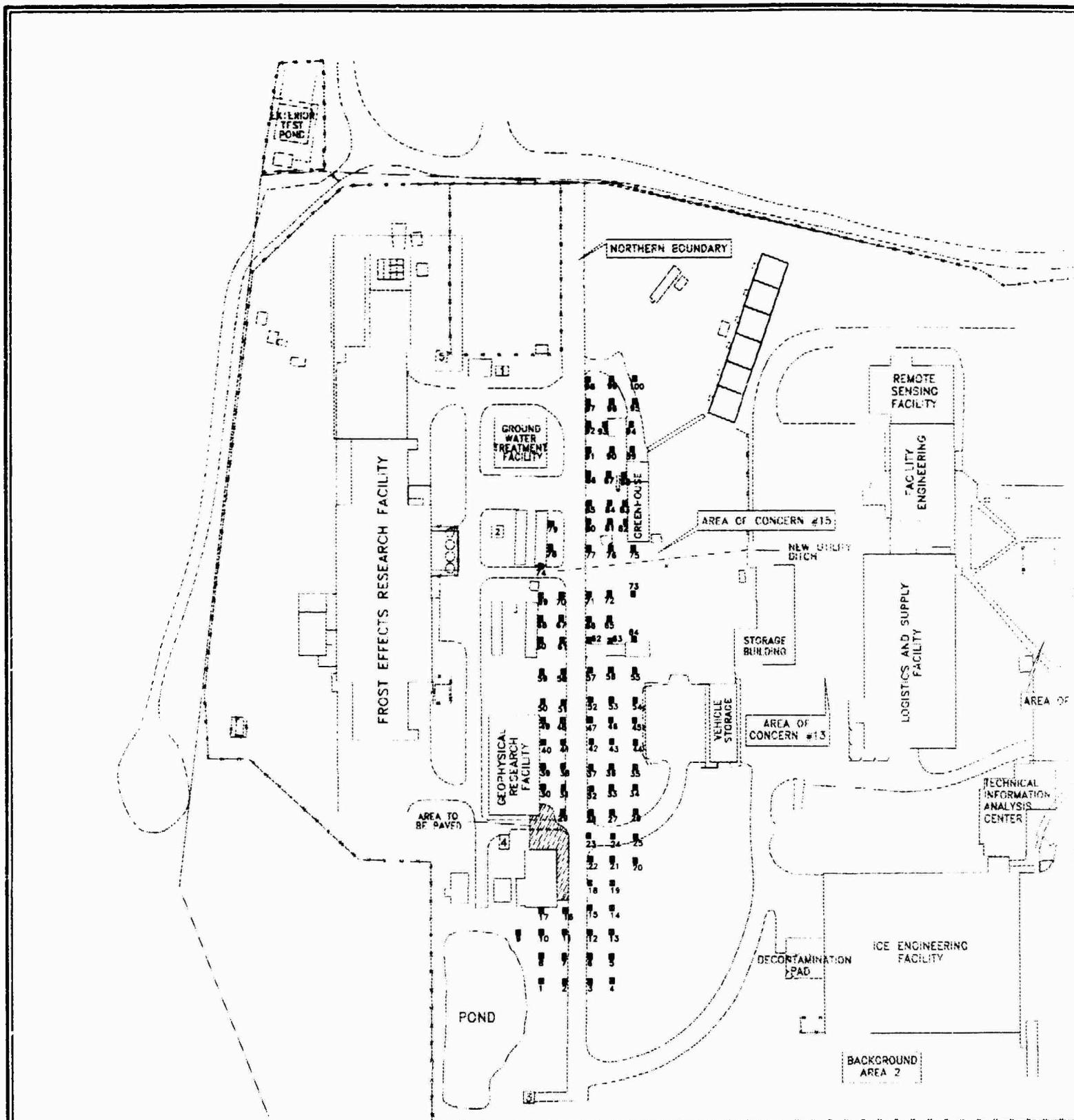
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Location	Boring Number	Auger Size IN ID	Sampling Interval FT BGS	Total Depth FT BGS	Disposition
AOC 13	13SB1	6 1/4	1.5-3.5 5.5-7.5* 17-19*	19	Grouted to surface
AOC 13	13SB2	4	20-22 30-32 50-52	52	Soil Ventilation Well installed
AOC 13	13SB3	4	5-7 25-27 45-47 70-72	72	Soil Ventilation Well installed
AOC 13	13SB4	4	5-7 20-22 90-92**	92	Soil Ventilation Well installed***
AOC 13	13SB5	4	9-11 20-22* 50-52*	52	Grouted to surface
AOC 15	15SB1	6 1/4	0-2 19-21 25-27 33-35	35.5	Grouted to surface
AOC 15	15SB2	6 1/4	5-7 24-26 28-30 46-48 62-64	64	Soil Ventilation Well installed
AOC 15	15SB3	4	4-6 34-36 54-56	56	Grouted to surface
AOC 15	15SB4	4	9-11 31-33 41-43 49-51*	51	Grouted to surface
AOC 15	CECRL19	6 1/4****	5-7 10-12 35-37 80-82	175	Bedrock Monitoring Well installed
AOC 16	16SB1	6 1/4	0-2 6-7.5 9-11.5	11.5	Grouted to surface

Notes:

- * Duplicate sample collected from this depth
- ** Sample analyzed for total petroleum hydrocarbons (TPH) only
- *** Due to drilling complications a new boring, 13SB4ALT, was drilled 6 feet northeast of 13SB4. This boring, with a stratigraphy and headspace comparable to 13SB4, was designated as the new location of the soil ventilation well.
- **** Mud rotary was implemented when the depth exceeded 120 feet below ground surface

IN ID Inches of the inner diameter of hollow stem augers
FT BGS feet below ground surface



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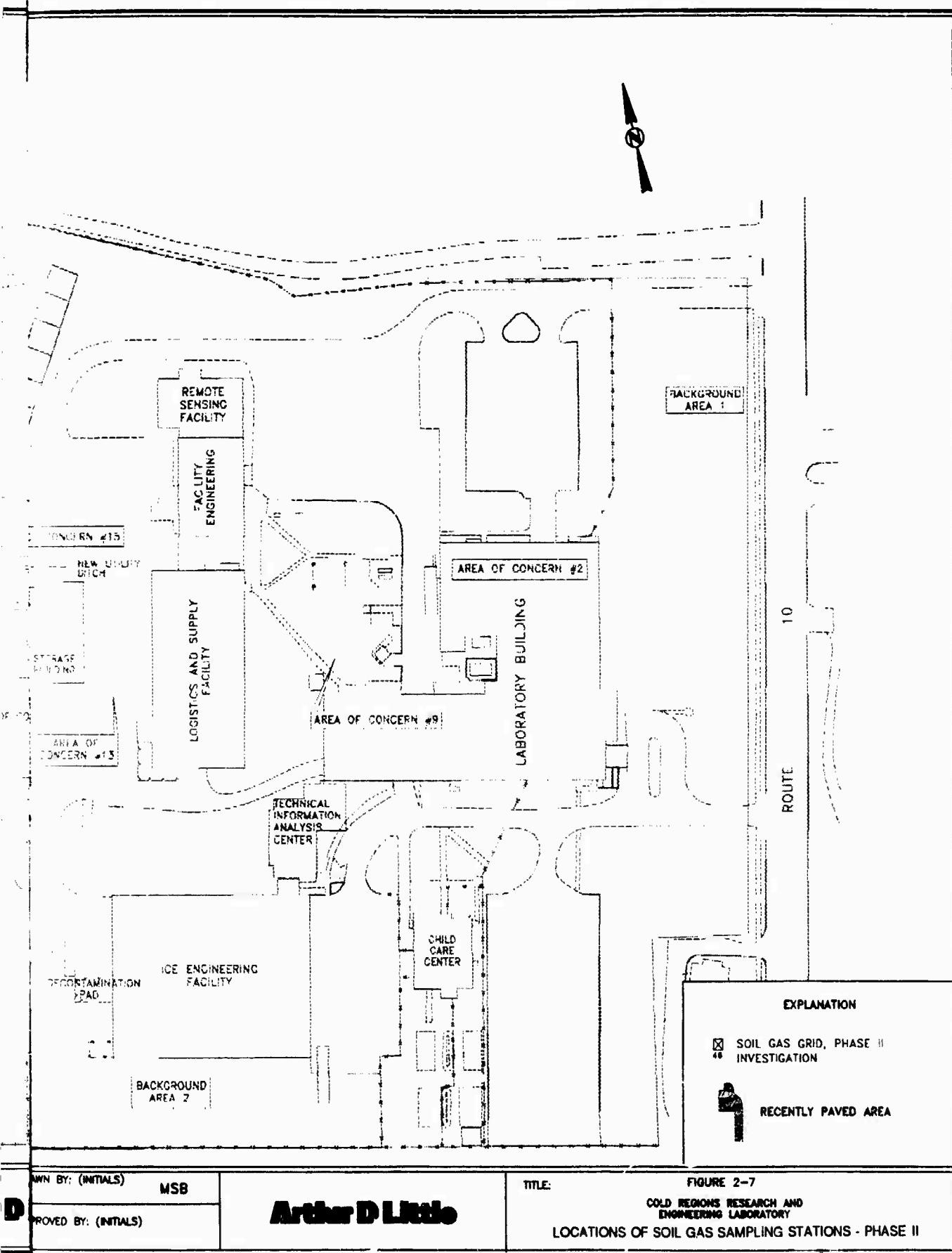
4 8 12 16 20 100 FEET

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- The samplers were sealed, wiped clean of loose dirt, and labeled at the site's surface.
- The samples were transported to the laboratory for mass spectrometer analysis.

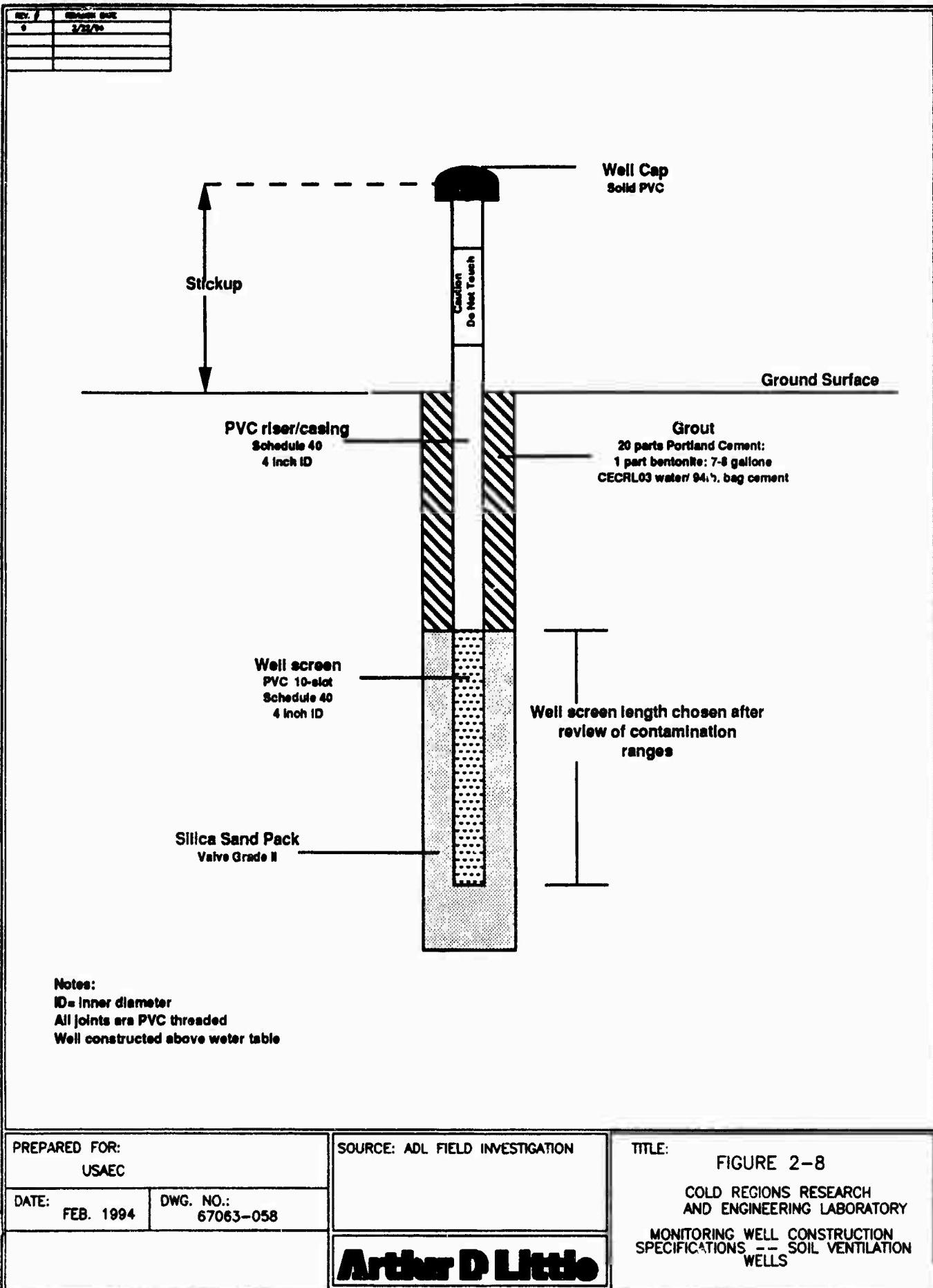
This procedure was followed for the 460 samplers installed during the Phase I field investigation and for the 100 samplers installed during the Phase II field investigation. Of the 100 samplers installed during the Phase II survey, 98 were retrieved. Sample 70 was found to be broken in the hole, and sample 9 was unable to be located due to paving activities.

2.4.4 Soil Vapor Monitoring Wells

Soil vapor monitoring wells were installed in 11 borings (2SB3, 2SB4, 2SB5, 2SB6, 9SB2, 9SB3, 9SB4, 13SB2, 13SB3, 13SB4ALT, and 15SB2) between July 21 and August 13, 1993 as part of the Phase II field investigation. The screened interval was placed across soil where headspace screening results for total VOCs were greater than 10 ppm. These wells were constructed with the objective of creating a means for future VOC ventilation from the vadose zone soil to the atmosphere.

Figure 2-6 shows the locations of the soil vapor monitoring wells. All wells were constructed to specifications approved by the USAEC geologist. Figure 2-8 is a schematic diagram of the construction specifications for the soil vapor monitoring wells. The individual monitoring well construction diagrams are presented in Appendix E. The following is a description of the procedure for soil vapor well installation at CRREL:

- Augers were removed from the soil boring after the completion of chemical and physical sampling.
- If the borehole remained open, PVC casing and 0.010 inch slot screen were lowered into the borehole to the desired depth. If the borehole failed to remain open, 6 1/4-inch ID augers were used to ream the hole, and the well was constructed inside the augers. The depth to the bottom of the screen was equal to the deepest interval where headspace screening results were greater than 10 ppm and extended to a maximum depth of 10 feet aboveground water. The top of the screen was placed at the depth where the first headspace screening results greater than 10 ppm were encountered.
- The well was centered in the borehole and secured with a Number 2 sand pack in the annulus. The sand pack extended to the top of the screen. The annular space between the borehole and the casing was filled with a cement-bentonite grout by the method described in Section 2.5.1.1.



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- PVC casing and riser pipe were set to approximately 2.5 feet aboveground surface at all wells, except those at AOC 13 (13SB2, 13SB3, and 13SB4ALT) where flushmount finishes were required. The flushmount wells were completed at a depth of 0.5 feet bgs.
- A PVC cap was placed on the top of the open stickup for all wells, and the outer PVC was labeled with the well number on all wells, except for the wells with a flushmount finish.
- A reflective caution sign was attached to the outside of each well with an aboveground stickup.

2.5 Ground Water Investigation

The ground water investigation was initiated by Ecology and Environment between January and April, 1992. This initial phase included supervising the installation of five overburden monitoring wells (CECRL07 to CECRL11) and one bedrock well (CECRL12), two rounds of ground water sampling of all CRREL wells, and water table measurements. An expanded ground water investigation was conducted by Arthur D. Little between July and December, 1993, which included supervising the installation eight additional monitoring wells -- three overburden and five bedrock (CECRL13 to CECRL20), three rounds of ground water sampling at all of the CRREL wells, in situ permeability testing of all monitoring wells, and water table measurements.

2.5.1 Monitoring Well Installation

Overburden wells CECRL07 to CECRL12 were installed between January 10 and February 20, 1992 by WTD Environmental Engineering of Schofield, Wisconsin. Well CECRL07 was installed to monitor background ground water conditions at CRREL, hydrologically upgradient from potential sources of site-related contamination. Well CECRL08 was installed at the northwest corner of the Main Laboratory Building, near the former TCE and fuel oil UST site (AOC 2). Well CECRL09 was installed near the Ice Well (AOC 9). Well CECRL10 was installed at the location of the former gasoline UST (AOC 6). Well CECRL11 was installed south of the former TCE surface disposal area (AOC 11). Well CECRL12 was installed between the CRREL production wells and the Connecticut River.

The second phase of well installation (CECRL13 to CECRL20) was conducted between July 7 and August 11, 1993 by Environmental Drilling, Inc., of Sterling, Massachusetts. Bedrock wells CECRL13, CECRL14, and CECRL15 were installed adjacent to overburden wells CECRL07, CECRL09, and CECRL08, respectively. In addition, two overburden-bedrock well couplets were installed -- one at the northern

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boundary on the lower terrace (CECRL17/16), and one adjacent to the west side of the greenhouse at AOC 15 (CECRL19/18). An overburden well (CECRL20) was installed at a second background location on the south side of the Ice Engineering Facility.

Table 2-4 shows the construction specifications for all of the monitoring wells at CRREL. Figure 2-9 shows the locations of all monitoring wells at CRREL. Appendix G contains the boring logs for the monitoring wells. Appendix E contains all of the monitoring well construction diagrams. All of the wells with the exception of CECRL16 were installed in accordance with *Geotechnical Requirements for Drilling, Monitor Wells, Data Acquisition, and Reports* (USATHAMA, 1987). Difficulties encountered during construction of CECRL16 necessitated deviations from the requirements (see well placement discussion in Section 2.5.1.2).

2.5.1.1 Overburden Well Installation. Monitoring wells CECRL07 to CECRL11 were installed using a Cantera Model CT-250 drill rig. Monitoring wells CECRL17, CECRL19, and CECRL20 were installed with a Failing F-6 drill rig. All of the overburden monitoring well boreholes were drilled with hollow stem augers. Installation of the overburden wells consisted of three main steps: borehole drilling, well placement, and well completion. The following is a description of these steps.

Borehole Drilling

The boreholes were advanced to desired depth using a 6 1/4 inch diameter (ID) hollow stem augers. For wells CECRL07 to CECRL12, geologic samples were initially collected with a 2-foot split spoon at 5-foot intervals, but the interval was increased at the direction of the USAEC after the general stratigraphy was established. For well CECRL20, samples were collected at 5-foot intervals to 127 feet, 11 feet above the bottom of the well. The presence of running sand prevented sampling of the bottom 11 feet. The procedure for geologic sampling is described in Section 2.2.4.

Unlike the other overburden monitoring well boreholes at CRREL, the boreholes for wells CECRL17 and CECRL19 were sampled to bedrock and subsequently grouted to the desired well completion depth of 108 feet. Borehole drilling at these locations proceeded using 4 1/4-inch diameter (ID) hollow stem augers. Samples were collected at 5-foot intervals to approximately 120 feet, where the use of hollow stem augers became difficult. Borehole advancement and sampling from this depth to bedrock (approximately 175 feet) was accomplished by mud rotary drilling. Three-inch inner diameter (ID) temporary casing was lowered to the bottom of the borehole. A 2 7/8-inch diameter tri-cone bit advanced the borehole as additional temporary casing was added. Split spoon samples were collected at 15-foot intervals down to bedrock. After geologic logging was completed, the casing and rods were pulled and

Table 2-4: Monitoring Well Construction Specifications

Well No.	Date Installed	Location Data		Elevation Data				Materials			
		Round	Northing (Y-Coord) M UTM	Eastling (X-Coord) M UTM	Ground Surface FT MSL	Top of PVC Casing FT MSL	Well Depth FT BGS	Bottom of Screen FT MSL	Top of Sandpack FT MSL	Top of Seal FT MSL	Send Type
CECRL07	02/03/92	1	4,844,585.88	719,932	523.0	525.61	179.4	354.0	359.0	364.0	No. 2
CECRL08	02/17/92	1	4,844,564.62	719,832.11	512.7	515.38	147	376.2	366.2	381.2	No. 2
CECRL09	02/12/92	1	4,844,545.13	719,760.53	507.2	509.75	137	380.7	370.7	385.7	No. 2
CECRL10	02/04/92	1	4,844,633.31	719,725.40	493.1	495.96	127.5	376.1	366.1	382.1	No. 2
CECRL11	02/15/92	1	4,844,565.05	719,669.29	476.5	479.14	117	370.0	360.0	375.0	No. 2
CECRL12	01/25/92	1	4,844,720.63	719,580.56	467.8	470.16	98.5	389.8	369.8	394.8	No. 2
CECRL13	07/30/93	2	4,844,586.7	719,929.5	523.0	524.90	203	330.0	320.0	335.0	No. 2
CECRL14	08/04/93	2	4,844,543.6	719,764.7	508.7	510.23	257	261.7	251.7	266.7	No. 2
CECRL15	08/03/93	2	4,844,567.9	719,833.5	512.6	514.52	190.3	332.3	322.3	337.8	No. 2
CECRL16	08/05/93	2	4,844,706.87	719,682.7	467.0	469.02	200	277.0	267.0	282.0	No. 2
CECRL17	07/20/93	2	4,844,708.2	719,686.9	467.1	468.72	108	379.1	359.1	384.1	No. 2
CECRL18	08/04/93	2	4,844,622.5	719,633.9	465.1	467.09	200	275.1	265.1	280.5	No. 2
CECRL19	08/04/93	2	4,844,619.0	719,663.0	465.0	466.72	108	377.0	357.0	382.0	No. 2
CECRL20	07/09/93	2	4,844,424.6	719,719.8	495.3	496.98	138	367.3	357.3	372.3	No. 2

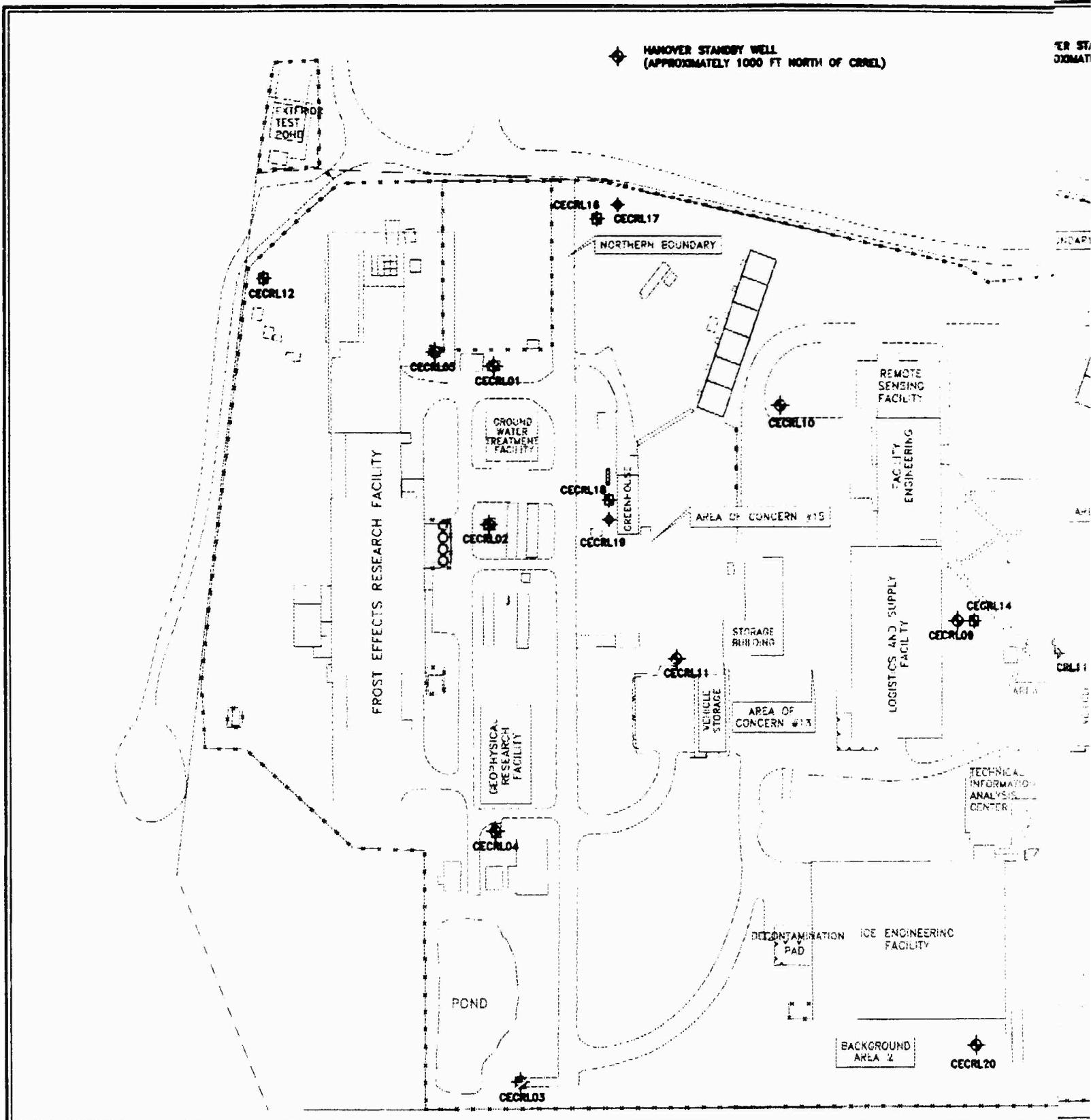
Notes:

M UTM Meters Universe Transverse Mercator
 FT feet
 MSL mean sea level
 BGS below ground surface

ROUND: 1=Ecology and Environment; 2=Arthur D. Little, Inc.

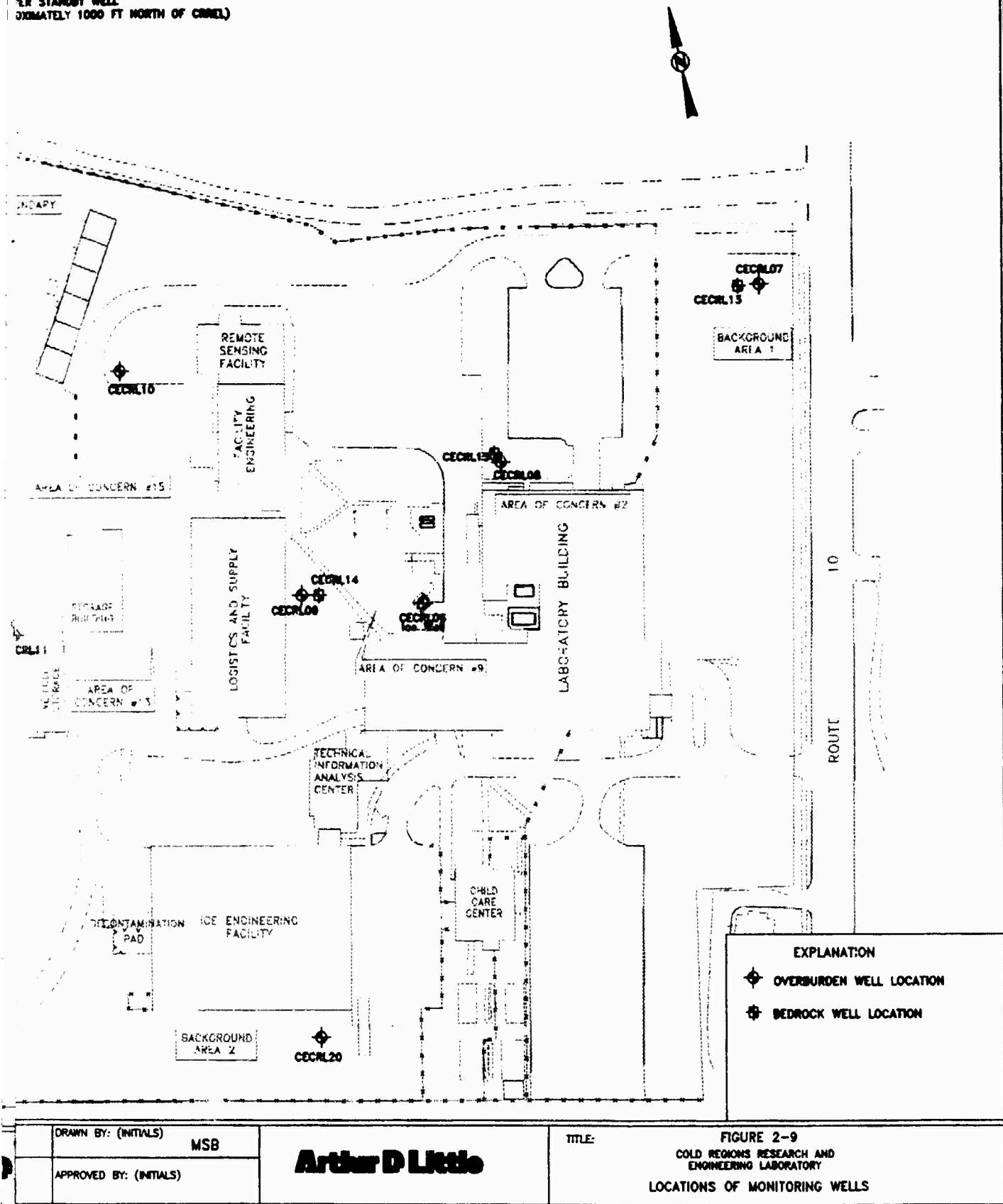
SEAL TYPE: 1=bentonite chips; 2=bentonite slurry
 6708361TEPS.rpt.trt.03/17/94

HANOVER STANDBY WELL
(APPROXIMATELY 1000 FT NORTH OF CRREL)



PREPARED FOR: USAEC		DRAWN BY: (INITIALS) MSB	
DATE: FEB. 1993	SCALE: 	DWG. NO. 67063-012	APPROVED BY: (INITIALS) Arthur D.

ER STANHOPE WELL
DIMATELY 1000 FT NORTH OF CECIL)



DRAWN BY: (INITIALS)

MSB

APPROVED BY: (INITIALS)

Arthur D Little

TITLE:

FIGURE 2-9
COLD REGIONS RESEARCH AND
ENGINEERING LABORATORY
LOCATIONS OF MONITORING WELLS

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the resulting 3-inch diameter borehole was grouted, in 50-foot lifts, to 109 feet -- 1 foot below the desired well completion depth.

All drill cuttings were disposed of in the manner described in Section 2.7.

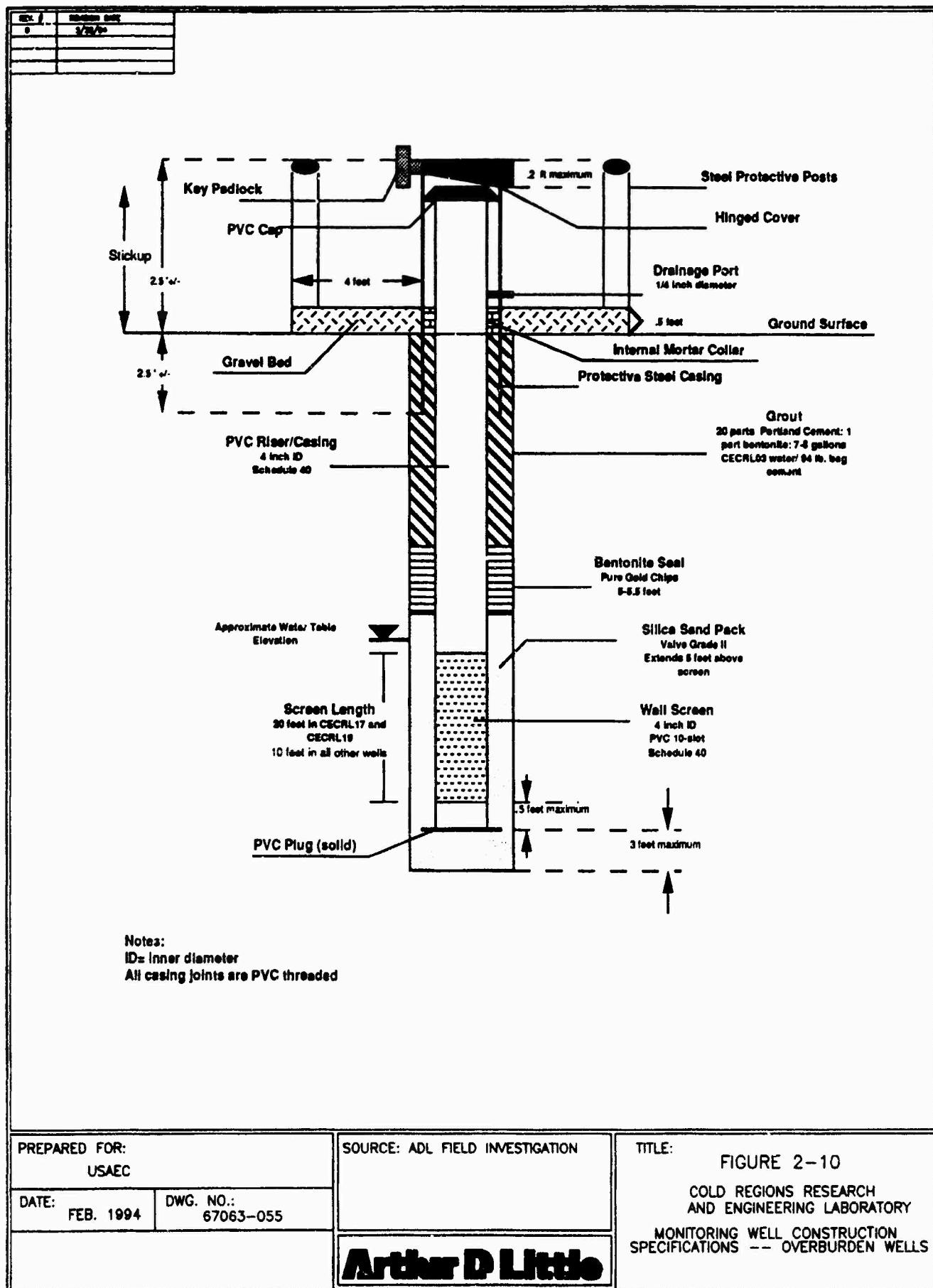
Well Placement

Figure 2-10 shows a generalized construction diagram for overburden monitoring wells installed at CRREL. All of the overburden wells were constructed of 4-inch ID Schedule 40 flush jointed PVC riser and 0.010-inch machine-slotted Schedule 40 PVC screen of the same diameter. The screen length in all of the overburden wells, except wells CECRL17 and CECRL19, is 10 feet. For wells CECRL17 and CECRL19, 20-foot screen lengths were used to increase ground water production from a thick silt layer.

All well construction was performed within 7 1/4-inch diameter (ID) augers. No. 2 sand was used for the sand pack material around the screen. The sand pack was set to a depth 5 feet above the top of the screen. The seal was composed of bentonite pellets that were placed to a depth of 5 feet above the top of the sand pack. The pellets were dropped individually to prevent bridging of the annulus. Where necessary, the pellets were hydrated with water derived from well CECRL03. After allowing the seal to set for a minimum of two hours, the grout was tremied into the annular space at 50-foot increments. The grout was composed by weight of 20 parts Portland Type II cement (94 lb bag), 1 part bentonite, and 7 gallons of water. Grout was mechanically mixed with a pump and tremied into the borehole. After each 50-foot lift, the grout set for four hours before placement of the next lift. This process continued until the grout was approximately 2.5 feet below the ground surface.

Well Completion

All of the overburden wells were completed in the same manner. A 5-foot long, 6-inch diameter protective steel casing was placed over the riser so that the top of the steel casing was approximately 0.2 feet above the top of the PVC cap. The steel casing was set into cement so that the total stickup of the protective steel casing was approximately 2.5 feet. After allowing the cement to set, a cement-sand mortar collar was placed in the annular space between the protective steel casing and the PVC riser to 6 inches above grade. A drainage hole was drilled in the protective steel casing, 6 inches above grade. Four protective cement-filled pickets were placed radially 4-feet from the well. The pickets were set approximately 3 feet into the ground, with a 3-foot stickup. The pickets and the wells were painted orange with a hand brush prior to installation. White paint was used for the well IDs. Following installation, four pieces of 2 inch by 8 inch lumber were placed around the pickets to form a box and gravel was placed on top of a plastic liner in the boxed area to 6 inches above grade.



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2.5.1.2 Bedrock Well Installation. Monitoring well CECRL12 was installed with a Cantera Model CT-250 rig. Monitoring wells CECRL13, CECRL14, CECRL15, CECRL16, and CECRL18 were installed using a Reich Model T-650-W drill rig, equipped with a mud rotary drilling assembly. Installation of the bedrock wells consisted of three main steps: borehole drilling, well placement, and well completion. Figure 2-11 is a schematic diagram showing the general construction specifications for bedrock wells installed at CRREL. Figure 2-12 is a schematic diagram for bedrock well CECRL16. The following is a description of these steps.

Borehole Drilling

Except for CECRL12, boreholes through the overburden were drilled with an 8 3/4-inch diameter carbide-tip tri-cone bit. The drilling fluid was a mixture of water from well CECRL03 and bentonite powder. With the exception of CECRL12, no samples were collected for geologic description since the bedrock wells were installed next to overburden wells where the stratigraphy was documented. However, samples were caught with a screen from mud returns at approximately 10-foot intervals and described on the logs. The overburden at CECRL12 was drilled and sampled as described in Section 2.5.1.1.

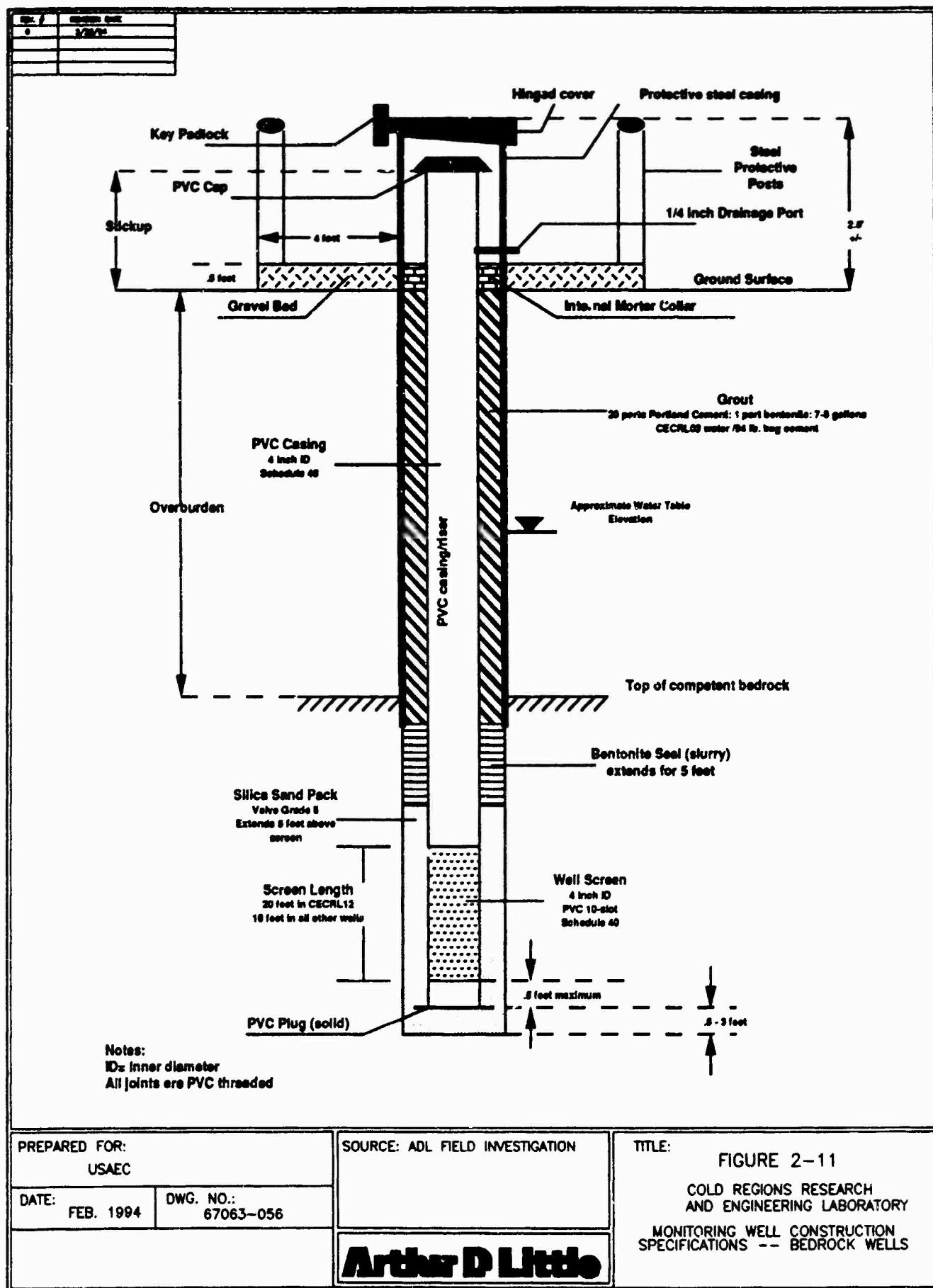
When bedrock was encountered, the boring was continued until competent bedrock was encountered, typically about 3 feet below the bedrock surface. The drilling assembly was removed from the mudded overburden borehole and a 6-inch (ID) steel casing was set to the bottom of the borehole. The drilling mud was then washed from the cased borehole using clean water from CECRL03.

The bedrock was cored following the methodology described in Section 2.2.3. Following the coring of bedrock, the mud rotary rig was repositioned over the borehole, and the hole was reamed to the desired depth (i.e., the bottom of the core borehole) using a 5 7/8-inch tri-cone bit. After reaming and washing of the bedrock borehole, the borehole was geophysically logged as described in Section 2.2.2. In some cases, the borehole had to be re-washed so that complete geophysical logs could be acquired.

Well Placement

The construction material and procedures were the same as those described for the overburden wells, except for the following:

- The placement of the 10-foot well screen was confirmed after a review of the rock cores and borehole geophysical logs. In all instances, these data indicated that water bearing fractures were present in the bottom 10 feet of each borehole. Therefore, all of the well screens, except for CECRL12, were placed near the bottom 10 feet of each borehole. A 20-foot screen was used in CECRL12 because of concerns with low recharge in the bedrock.

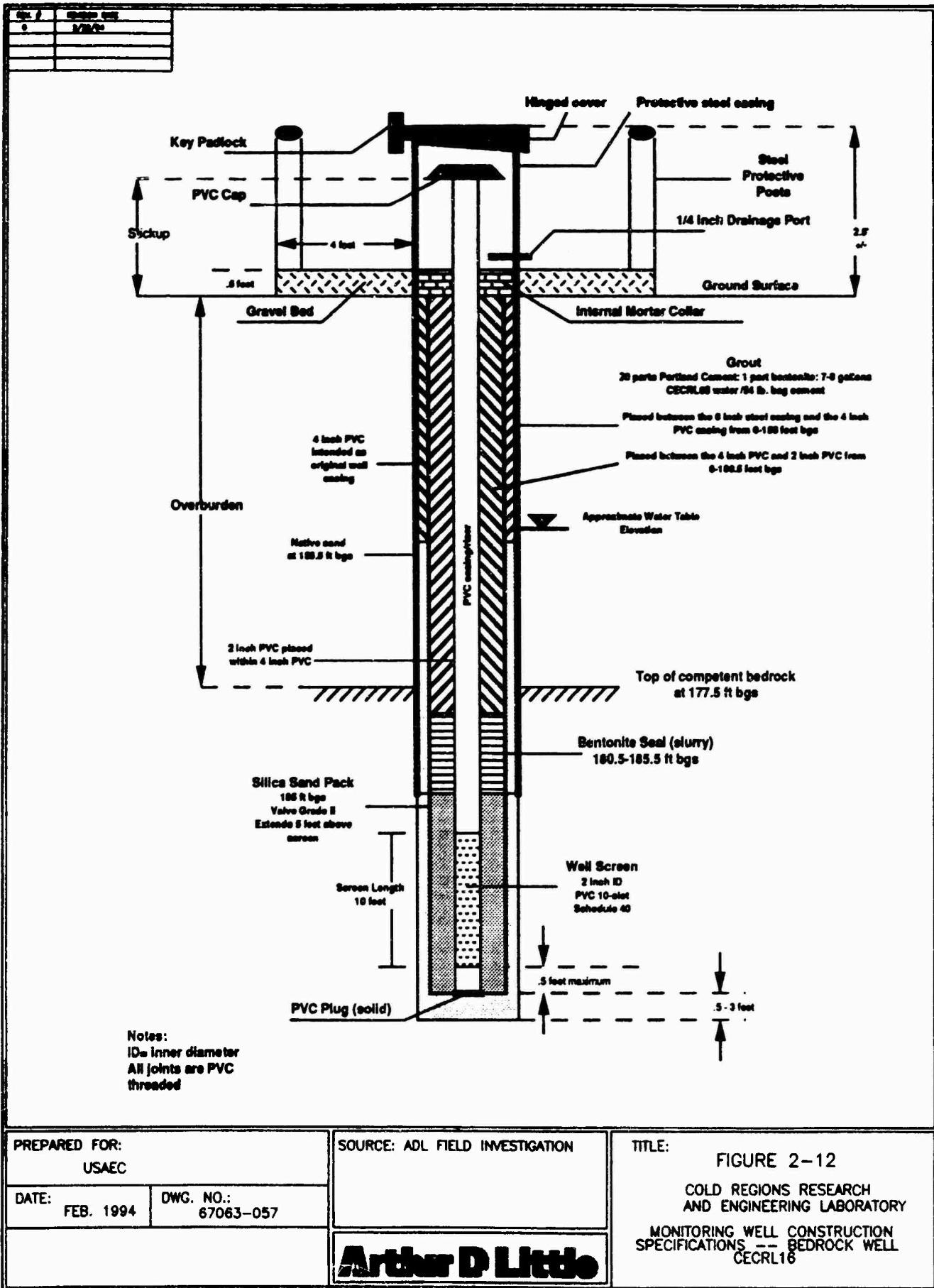


PREPARED FOR:
USAEC

DATE: FEB. 1994 DWG. NO.: 67063-056

FIGURE 2-11

COLD REGIONS RESEARCH
AND ENGINEERING LABORATORY
MONITORING WELL CONSTRUCTION
SPECIFICATIONS -- BEDROCK WELLS



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- In all of the bedrock wells except CECRL16, the seal consists of a bentonite slurry (Table 2-4) emplaced with tremmie pipe. The slurry was used in lieu of pellets to prevent bridging of the annulus above the desired depth of the seal, which was often well below the water table. In all wells except CECRL16, the top of the 5-foot seal was set several feet below the top of the bedrock.
- During the drilling of the bedrock section of well CECRL16, large fractures in the bedrock were encountered beneath where the 6-inch diameter steel casing was set. These fractures apparently became conduits for sand to migrate from the overburden into the borehole. After consultation with the USAEC geologist and Project Manager, repeated attempts to clean the borehole were made and a 4-inch PVC screen was set within 2 feet of the bottom of the borehole (202.5 feet bgs). However, running sands migrated up the annulus to approximately 158 feet bgs and restricted the placement of the sand pack, thus preventing proper construction of the well. Since the 4-inch PVC well could not be pulled and the influx of the native sand could not be mitigated, a 2-inch diameter well was constructed inside the 4-inch well. The 2-inch diameter well was constructed within 3-inch diameter temporary casing so that the sand pack and the bentonite seal could be set at the desired depths. The casing was pulled in increments as the sand pack and seal were set.

Well Completion

The bedrock wells were completed in the same manner as the overburden wells, except for the following deviation:

- In all bedrock wells except for well CECRL12, the protective steel casings are an extension of the 6-inch diameter steel casings. Well CECRL12 completed in the same way as the overburden wells.

2.5.1.3 Well Development. Monitoring wells CECRL07 through CECRL12 were developed between January 28 and February 20, 1992. Monitoring wells CECRL13 to CECRL20 were developed between July 20 and August 11, 1993. The purpose of well development is to restore the natural hydraulic properties of the formation in the screened zone. Well development logs are presented in Appendix H.

Where no deviations were made to USAEC specifications, the general procedures for well development were as follows:

- The volume necessary for removal from each well was calculated based on measurements of water level, well depth, and well construction information. This volume was equal to five times the standing water in the well and saturated annulus (assuming 30 percent porosity) plus five times the volume of drilling fluid lost.

- A submersible pump was inserted into the middle of the screened interval.
- The first water from each well was sampled for water quality parameters (pH, specific conductivity, temperature, and turbidity) using a Horiba Model U-10.
- The flow of water from each well was regulated to determine a suitable pumping rate and discharged to a 55-gallon drum. The headspace of the water was screened at approximately 25-gallon intervals with a Microtip PID. If the screening results were less than 5 ppm, the water was discharged to the ground. If the screening results were greater than 5 ppm, the water was handled as investigation-derived waste (Section 2.7).
- During well development, the submersible pump was moved up and down within the well screen. At least two measurements of water quality parameters were collected during development.
- At the completion of well development, a final water sample was tested for water quality parameters. This sample was delivered to the CRREL Environmental Engineer.

In some instances the desired volume of water to be removed was not satisfied. Such deviations from the USAEC requirements were approved by the USAEC geologist and Project Manager. The large amounts of drilling fluids used during well drilling and/or the slow recharge encountered at several of the wells (particularly the bedrock wells) prohibited removing the desired amount of water at CECRL07, CECRL10, CECRL11, CECRL12, CECRL13, CECRL14, CECRL15, CECRL17, and CECRL18. In the case of bedrock wells, the wells were pumped dry a minimum of three times over a 2- to 3-day period and until stabilization of water quality parameters was observed. Water clarity was achieved in most wells, except for CECRL17 and CECRL19, which were screened in a gray silt.

Bedrock wells CECRL13 and CECRL16 were pre-developed prior to well installation. Pre-development of these wells was deemed necessary since mud was used to seal large bedrock fractures encountered during drilling and coring. Pre-development consisted of pumping the water until it ran clean, indicating satisfactory removal of the drilling mud.

2.5.2 Ground Water Sampling

Five rounds of ground water sampling were conducted at CRREL during the field investigation. The first and second rounds of sampling occurred during the Phase I field investigation (March 6 to 13, 1992 and April 7 to 10, 1992) and included the production wells (CECRL01 through CECRL05), the Ice Well (CECRL06), the monitoring wells (CECRL07 through CECRL12), and the Town of Hanover supply

well. The third, fourth and fifth rounds of ground water sampling occurred during the Phase II field investigation (August 23 to 27, 1993, September 27 to October 1, 1993, and November 29 to December 3, 1993) and included all Phase I sampling locations, and the newly installed monitoring wells CECRL13 to CECRL20. During the fourth round, production well CECRL02 was not operational and could not be sampled. During the fifth round, production well CECRL01 was not operational and could not be sampled.

The analytical program for ground water sampling is presented in Appendix B. All ground water samples were analyzed for VOCs and TPH. In addition, samples collected during rounds 3, 4, and 5 were analyzed for BTEX. Wells CECRL18 and CECRL19 were also analyzed for naphthalene during rounds 3, 4, and 5. Field QC samples were collected as described in Section 2.6.4.1.2.

Ground water sampling and analytical protocol followed the USAEC specifications (USATHAMA, 1987). For rounds 1 and 2 these procedures are defined in the Ecology and Environment Field Sampling Plan (FSP) (1991) and Quality Assurance Project Plan (QAPjP) (1991b). For rounds 3, 4 and 5, these procedures are defined in the Arthur D. Little Work Plan and Quality Control Plan (1993). The general procedure for ground water sampling was as follows:

- All monitoring wells were allowed to remain undisturbed for a minimum of two weeks after well development prior to sampling.
- After opening the well, total VOCs were measured at the well head by a PID and recorded in the field notebook.
- The well was prepared for purging. All well purging information was recorded on ground water sampling logs (Appendix I). The monitoring well purging process consisted of the following steps:
 - The depth to ground water, from the top of the PVC casing, was measured and recorded to the nearest 0.01 feet.
 - The volume of ground water to be purged was calculated as 5 times the volume of the saturated zone of the well plus 5 times the saturated annular space (assuming a 30 percent porosity).
 - A decontaminated submersible pump was lowered to within a few feet from the bottom of the well. Purge water was discharged to a 55-gallon drum and the rate of discharge/drawdown was noted by the technician. Toward the end of the purge cycle, the discharge rate was lowered to reduce to cascading of water prior to sample collection.

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- Ground water quality parameters were measured with a Horiba U-10 meter at a minimum of three times during purging: once at the beginning, once in the middle, and once at the end. These parameters were pH, conductivity, and temperature during first two rounds and pH, conductivity, turbidity, temperature, and dissolved oxygen during the third, fourth, and fifth (Arthur D. Little) rounds.
- After purging was complete, the submersible pump was removed from the well and sampling commenced.
- Purging of the production wells involved discharging ground water to the surface through an outlet in the pump house. The water was allowed to run for a minimum of five minutes before ground water quality parameters were measured. Ground water quality measurements were collected once at each production well for the parameters described above. During rounds one and two, the purging of CECRL02 consisted of removing 5 gallons of water with a pre-cleaned Teflon bailer.
- The Ice Well was not purged prior to sampling. Ground water quality measurements were not collected.
- All of the monitoring wells and the Ice Well (CECRL06) were sampled using precleaned Teflon bailers. During rounds 1 and 2, production well CECRL02 was also sampled with a bailer. The remaining production wells and the Hanover municipal well were sampled through a spigot. Wells were sampled by the following procedure:
 - All prelabeled bottles were triple rinsed with well water prior to sample collection, either with bailed water or water from a sampling spigot.
 - The samples for VOC analysis were collected first, followed by samples for BTEX, naphthalene (if sampled), and TPH. The VOC and BTEX samples were preserved with hydrochloric acid to a pH<2.
 - Final ground water parameter measurements were recorded after sampling was completed.
- All samples were securely packed into an approved cooler with sufficient ice and blue ice to chill the samples to 4 degrees Celsius.
- All samples were shipped to the laboratory by an overnight delivery service on the day that they were collected.

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- All purge water was handled as described in Section 2.7.

Field conditions required several amendments to the purging procedures described above for the monitoring wells. This was necessary because many of the monitoring wells, particularly the bedrock wells, have extremely slow rates of recharge.

Permission was granted by the USAEC geologist to amend the purging procedure for those wells that required more than four hours to purge. For these wells, the purging procedure was to pump the well dry three times over the course of at least four hours. Monitoring wells that have had historically poor recharge rates are CECRL10, CECRL14, CECRL15, CECRL17, CECRL18, and CECRL19.

2.5.3 Aquifer Testing

In situ permeability tests (slug tests) were conducted on all of the monitoring wells, except CECRL16, to determine hydraulic conductivity. These tests were performed between September 7 and 10, 1993. The slug length dimensions used during aquifer testing remained constant, with 3 1/2-inch (diameter) by 30-inch (length) slugs used for all wells. All slugs were composed of solid PVC. The Bouwer and Rice method was chosen for interpretation as it allows for the determination of saturated hydraulic conductivity of aquifer materials in both fully and partially penetrating wells. A summary of the well and test parameters for the hydraulic conductivity analysis is presented in Appendix J along with the field data and results.

All slug tests were performed in accordance with the Work Plan (Arthur D. Little, 1993) and the ADL SOP-4018. In general, the slug tests require a raising and lowering of the static water level in the well to be tested. To achieve this, the following procedure was employed:

- Technical personnel arrived at the well site and recorded the well conditions, total VOCs, and static water level.
- A 10.0 psi transducer cable was secured and the data logger programmed with the site specific test parameters. The slug was then lowered into the well and the falling head test was performed in accordance with ADL SOP-4018.
- After equilibrium or 80 percent recovery was achieved, the slug was raised and the rising head test was performed in accordance with the ADL SOP.
- At the completion of the testing, the slug was removed from the well, all equipment was decontaminated, and the data were downloaded from the datalogger.

CECRL16 was not tested due to the speed of its recharge. As pumping with a submersible pump resulted in minimal drawdown, it was decided that slug testing would be ineffective.

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2.5.4 Water Level Measurements

Water level measurements were collected from all of the monitoring wells to construct water table contour maps and potentiometric surface maps for the bedrock portion of the aquifer. These data were also used to determine vertical hydraulic gradients where well couplets exist and to determine the hydraulic relationship between the Connecticut River and well CECRL12.

Ground water measurements followed ADL SOP USA-4012 and the USAEC specifications (USATHAMA, 1987). Ground water measurements were collected prior to the initiation of each ground water sampling round. The depth to ground water was measured to 0.01 feet from a notch at the top of the PVC casing using an electronic water level indicator.

Long-term monitoring of ground water at CECRL12 and the Connecticut River was performed between October 1 and 5, 1993. The monitoring was accomplished with an electronic data recorder set to simultaneously record water levels at both locations through two pressure transducers. Water levels at each station were referenced to their respective elevations. For well CECRL12, this elevation was calculated from surveyor information. For the Connecticut River, a minimum elevation was recorded from hourly water level measurements at the Wilder Dam.

2.5.5 Ice Well Measurements

The depth to ice in the Ice Well (CECRL06) was measured on several occasions during the field investigation. During the Phase I field investigation, the top of the ice was measured at 63 feet bgs. During the Phase II field investigation, measurement was recorded at 190.2 feet bgs. It is not known whether the later measurement represents the ice surface or the bottom of the well, but it is clear that a significant melting occurred between the measurements.

2.6 Analytical Program

This section describes the chemical analysis of soil and water samples taken during the Phase II RI at CRREL. A discussion of the Phase I analytical program is included in the Phase I Report.

The chemical analysis program for the Phase II RI was directed towards generating data from field and laboratory tests that defined contamination characteristics at the CRREL site. Specific sets of analytes for laboratory analysis were specified for each sample collected from the site. The chemical analysis program was designed to obtain quantitative data on the presence of selected chemicals at detection limits consistent with USAEC target reporting limits and federal and state regulations. In addition to measuring the concentration of specific analytes, a library search was executed for non-target sample components for the purpose of tentative identification. For this

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purpose, the 1989 (or more recent) release of the NIST/EPA/MSDC mass spectral library, containing 50,000 spectra, was used.

Volatile Organics (GC/MS)

The methods used for the detection of VOCs are USAEC Method LM23 for soils and USAEC Method UM21 for water. These methods are based on EPA Method 8240 and are used to determine VOCs in a variety of matrices. An inert gas is bubbled through a 5-milliliter water sample or a 5-gram soil sample contained in a specially designed purging chamber at ambient temperature. The purgeable organics are efficiently transferred from the aqueous phase to the vapor phase. The vapor is swept through a sorbent trap where the purgeables are trapped.

After purging is completed, the trap is heated and backflushed with the inert gas to desorb the purgeables onto a gas chromatographic column. The gas chromatograph (GC) is temperature programmed to separate the purgeables, which are then detected with a mass spectrometer (MS).

All organic compounds of greatest apparent concentration for the purgeable and extractable fractions, are tentatively identified via a forward search of the NIST/EPA/MSDC library (substances with responses less than 10 percent of the internal standard are not required to be searched in this fashion). Only after visual comparison of sample spectra with the nearest library searches will the mass spectral interpretation specialist assign a tentative identification.

If, in the technical judgment of the mass spectral interpretation specialist, no valid tentative identification can be made, the compound is reported as tentatively identified compound (TICs). When possible, the mass spectral specialist provides additional classification of the TIC (e.g., TIC aromatic, TIC hydrocarbon, TIC acid type, TIC chlorinated compound). TICs that can be identified with greater than 95 percent certainty are reported to IRDMIS using the USAEC test name code. TICs that cannot be identified with greater than 95 percent certainty are reported to IRDMIS using UNKXXX, where XXX is an assigned number that is determined based on the relative retention time. This technique lends some assurance that major organic species that may be present in the CRREL samples will be detected and reported.

Benzene, Toluene, Ethylbenzene, and Xylene (GC)

The methods used for the detection of BTEX are USAEC Method AA9 for soils and USAEC Method AV8 for water. These methods are based on EPA Method 8020 to determine concentrations of benzene, toluene, ethylbenzene, and xylene in soils, sediments, and water. This method is similar to Method 8240 described above, however the GC system uses flame ionization detector (FID) to detect these compounds instead of a mass spectrometer.

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TPH (GC/FID)

This method is designed to identify and quantify petroleum product contaminants and can be applied to water, soil, and waste samples. The sample is extracted in methylene chloride, and the extract is concentrated and then analyzed by capillary column gas chromatography with flame ionization detection. A result is reported for the TPH detected, and a qualitative identification of the contaminants is made. This method is based in part on EPA Method 8015 and ASTM D3328-78 (USAEC does not require performance demonstration of this method). It is intended to provide higher resolution than these methods and a greater amount of qualitative information. The technique has been applied to a wide variety of environmental investigations. The advantage of this method over EPA Method 418.1 for the determination of TPH by infrared (TPH-IR) is that it provides not only quantitative information but qualitative information as well. Thus, the identity of the contaminant is established and can help in the determination of the source for and transport of the petroleum product in the aquifer or vadose zone. EPA Method 418.1 is also very susceptible to interferences, specially by hydrocarbons that are not petroleum in origin.

Naphthalene (GC/MS)

The method used for the detection of naphthalene in water is USAEC Method UM25. This method is based on EPA Method 8270 to determine the concentration of SVOCs (e.g., naphthalene) in extracts prepared from all types of solid waste matrices, soils, and ground water. For the analysis, a measured volume of sample, approximately 1 liter for aqueous samples or 30 grams for soil and sediment samples, is extracted with methylene chloride. The methylene chloride extract is dried, concentrated to a volume of 1 milliliter, and analyzed by GC/MS.

As an indicator of a broader spectrum of oil-related contamination, TPH was measured at selected locations. This technique indicates the presence of contamination from a variety of oils and/or fuels that may have been used at CRREL. Tests for total volatile organic emissions were also conducted in the field to provide "real time" information about ground water well development and the presence of broad indicators of contamination in soil, water, and air (headspaces and/or soil gases).

Appendix K includes a listing of the analyses performed on the samples collected during the CRREL investigations and a complete list of analytes. For each of the analyses, the reference analytical method is provided. Most of the analyses cited in Appendix K were performed using USAEC-performance demonstrated methods. The referenced USAEC-performance demonstrated methods are unique to DataChem Laboratories and all USAEC analyses are conducted according to the requirements of the specific method, without deviation. Details of the USAEC analyses, including the certified reporting limit (CRL) for each analyte, are also provided in Appendix K. A

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copy of the complete USAEC-approved DataChem method for each of these analyses is maintained in the Arthur D. Little files for this project.

2.6.1 Analytical Parameters

In order to provide a common point of reference for all projects and to provide a means of evaluating laboratory performance, USAEC prescribes the use of standardized methods for commonly encountered analytes. These methods contain all analytical parameters relevant to the Phase II RI. The standardized methods are based on published methods of analysis, USAEC standing methods, or past USAEC experience (e.g., for military unique compounds). Methods have been evaluated in terms of sound analytical practice and applicability to environmental projects. In addition to specifying sample preparation and analysis, each method also specifies calibration procedures and frequency, calibration check acceptance criteria, methods of preparing standard solutions, and preparation of Quality Control (QC) samples.

The primary laboratory used for this analytical program was DataChem Laboratories, a USAEC-performance demonstrated laboratory in Salt Lake City, Utah.

Appendix K provides a list of USAEC-performance demonstrated methods used for the determination of the analytical parameters for this task, the methods used, and equivalent EPA methods where they exist. The method numbers are specific to the project and to DataChem.

2.6.2 Field Analyses

The analyses that could be performed in the field are conductivity, pH, temperature, and turbidity. Each of these analyses was performed in the field using a single instrument, a Horiba Model U-10 Water Quality Meter. This instrument is factory calibrated semiannually and is checked daily for pH calibration. Daily calibration of all other parameters was performed by the instrument electronically during the pH assessment. If the instrument's daily self-calibration did not respond within programmed responses, a message was sent to the LCD indicating which parameter failed to meet the calibration criteria. When this occurred, simple field maintenance was performed and the instrument was recalibrated. Confirmatory pH data were collected using pH paper.

2.6.3 Quality Assurance/Quality Control (QA/QC)

DataChem, the laboratory performing the analytical work for the Phase II RI, has been required to implement QA/QC procedures specified in the USAEC QA Program. QA/QC protocols help ensure conformance with authorized policies, procedures, and sound practices. These practices provided a consistent framework for the generation of the analytical data in support of the Phase II RI. The following section describes the procedures implemented to achieve the objectives of the USAEC QA Program.

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2.6.3.1 Laboratory Method Approval. In accordance with the USAEC QA Program, laboratories require formal performance demonstration for the analytical methods conducted in association with site investigations. These analytical methods are provided in Appendix K. USAEC requires that a laboratory must demonstrate proficiency in performing analyses for specific parameters by submitting data from runs of pre-performance demonstration calibration standards. Performance samples are then sent for analysis to the laboratory from USAEC. The concentrations of the analytes in these samples are not known by the laboratory. The data are then sent to USAEC, where the precision and accuracy of the analyses are determined. Performance demonstration is either awarded or denied to the laboratory based on this performance. A performance demonstration methods code is assigned to each method and reported with results.

Methods are approved in four different ways (Class 1, Class 1A, Class 1B, or Class 2), depending on specific project requirements and analytical method types, subject to USAEC approval. The difference between classes is the procedure used to characterize laboratory performance of the method. Class 1A approval is reserved exclusively for GC/MS methods while Class 1B is reserved for low sample throughput methods (non-GC/MS). Designation of a method as Class 1B can only be made by the USAEC Chemistry Branch following the review and approval protocol. Class 1 is reserved for non-GC/MS methods with a sample throughput comparable to that of the Class 1A. Class 2 approval is used for methods that screen for the presence or absence of contaminants.

Some methods, such as those for alkalinity, total organic carbon, total suspended solids, and TPH, do not require performance demonstration. USAEC recognizes standard EPA protocols or internal laboratory methods for these parameters. Laboratories are required to submit information on procedures for analyzing samples using these methods to the USAEC Chemistry Branch before they are implemented.

2.6.3.2 Laboratory Methods Quality Control. QC data are necessary to determine precision and accuracy and to provide quantitative evidence that the method is performing comparably or better than when documented during method development and performance demonstration. Laboratory-based control samples consist of standards, surrogates, spikes, and blanks. Data generated from control samples that are included in each lot are plotted on control charts to monitor day-to-day variations in routine analyses. For this program DataChem followed the approach described by the *USATHAMA Quality Assurance Program* for performance methods with respect to laboratory control samples. For methods not requiring performance demonstration by USAEC, DataChem followed the specific method directives. Generally, a blank, a spike, and a duplicate were included in each lot of 20 or fewer samples.

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The types of laboratory control samples and the minimum acceptable performance for methods not requiring performance demonstration by USAEC for USAEC projects are briefly described below.

2.6.3.2.1 Laboratory Blanks. In addition to field blank samples, three types of blanks may be analyzed in the laboratory: calibration blanks, method blanks, and reagent blanks. Method blanks and reagent blanks are used to assess laboratory procedures as possible sources of sample contamination. Calibration blanks establish the analytical baseline against which all other blanks are measured.

- Method Blanks are laboratory blanks that correspond to the first step in sample preparation and, as such, provide a check on contamination resulting from sample preparation and measurement activities. For USAEC-performance demonstrated methods, method blanks for water and soil samples consist of a standard matrix that is subjected to the entire sample procedure as appropriate for the analytical method being utilized. For methods not requiring performance demonstration by USAEC, the method blank is typically an appropriate volume laboratory water carried through the entire preparation and analysis procedure.
- Reagent/Solvent Blanks are closely related to method blanks, but they do not incorporate all sample preparation materials and analytical reagents in one sample. When a method blank reveals significant contamination, one or more reagent blanks may be prepared and analyzed to identify the source of contamination.
- Calibration Blanks consist of pure reagent matrix and are used to zero an instrument's response to the level of analytes in the pure reagent matrix. They do not provide a direct indication of the types, sources, or levels of contamination, but they establish the analytical baseline.

2.6.3.2.2 Laboratory Duplicates. Laboratory duplicate samples are defined as two sample aliquots taken from the same sample container and analyzed independently. The results of these analyses serve as an indicator of the precision of the method and the sample results. The frequency of these duplicates is specified in the performance methods. For methods not requiring performance demonstration by USAECs, duplicates were prepared with the frequency specified in the referenced method.

2.6.3.2.3 Calibration Standards. A calibration standard is prepared in the laboratory by dissolving a known amount of a pure compound in an appropriate matrix. The final concentration calculated from the known quantities is the true value of the standard. The results obtained from these standards are used to generate a standard curve and thereby quantify the compound in the environmental sample.

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2.6.3.2.4 Spike Sample. A sample spike is prepared by adding to an environmental sample or standard matrix (for USAEC performance demonstrated methods, before extraction or digestion), a known amount of pure compound of the same type that is to be assayed for in the analysis. The spike may also be a surrogate compound for the analyte of interest. These spikes simulate the background and interferences found in the actual samples and provide a mechanism to verify overall method performance. The calculated percent recovery of the spike is taken as a measure of the accuracy of the total analytical method. For USAEC performance demonstrated methods, between one and three spiked samples, as specified in each method, were included in each lot. For methods not requiring performance demonstration by USAEC, spiked samples were analyzed with the frequency specified in the method.

2.6.3.2.5 Internal Standard. An internal standard is prepared by adding a known amount of pure compound to the environmental sample; the compound selected is not one expected to be found in the sample, but is similar in nature to the compound of interest. Internal standards are added to the environmental sample just prior to analysis.

2.6.3.2.6 Concentration and Frequency of Control Samples. For Class 1 methods, in addition to the method blank, three independently prepared spiked standard matrix QC samples shall be included in each lot. Two spiked standard matrix QC samples contain all control analytes at a concentration near the upper limit of the certified range. The third spiked standard matrix QC sample is prepared at two times the CRL.

Class 1A methods require an independently prepared spiked standard and natural matrix sample included in each lot. These are broken down into a single standard matrix QC sample, a method blank/spike, containing all surrogate analytes spiked at approximately 10 times the CRL. For the method blank/spike, surrogate results represent the QC spike, while unspiked non-surrogate results represent the method blank. Spiked natural matrix QC samples consist of every field sample spiked with all USAEC approved surrogate analytes at approximately 10 times the CRL.

Class 1B methods require an independently prepared spiked standard matrix QC sample included in each lot, in addition to the method blank. The spiked standard matrix QC sample contains all control analytes at a concentration near the upper limit of the certified range.

Class 2 methods require one spiked QC sample in each lot in addition to the method blank. The concentration of the spiked sample is the CRL from the approved method, which establishes the level that can be distinguished from a blank.

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2.6.3.3 Data Reduction and Validation. The laboratory is initially responsible for the accuracy and completeness of the Phase II RI analytical data packages. All data submittals to USAEC first underwent the review process. This review included checks on the data quality for completeness and accuracy of laboratory data; compliance with quality control limits and holding times; and correlation of laboratory data to associated laboratory tests.

2.6.3.3.1 Data Reduction. All processes that change either the form of expression or quantity of data values or numbers of data items are part of the data reduction process.

Raw data from quantitative analysis procedures such as GC, GC/MS, High Performance Liquid Chromatography (HPLC), Inductively Coupled Argon Plasma (ICAP), and Ion Chromatography (IC) generally consist of peak areas (or peak heights) for the analytes of concern, internal standards, and surrogates. These raw data are converted to concentrations by use of calibration curves or relative response factors that relate peak area to the quantity of analyte introduced in the instrument. The calibration procedures are generally less rigorous for field methods than for methods performed in the laboratory.

Generally, data were collected during the analysis of samples either into computer-based data files or onto hardcopy sheets, which, in turn, were either machine generated or hand written. In reporting results, rounding to the correct number of significant figures (this varies with the method) occurred only after all calculations and manipulations were completed. For dilutions, the number of significant figures was reduced by one. Each analytical method referenced in Appendix K describes the data reduction procedures for laboratory analysis results. In addition, the methods describe the correct procedure for using method blank results.

All uncorrected values less than the certified reporting limit, including no response, were reported as "less than" (LT) the reporting limit. Results of the analyses were entered into the USAEC IRDMIS, as outlined in the *Installation Restoration Data Management User's Guide* (USATHAMA, 1992). Analytes from methods not requiring performance demonstration by USAEC were reported using detection limits documented in the appropriate method and were flagged for data entry into the IRDMIS database.

The abbreviation "GT", which appears on the data summary tables for several samples, stands for "greater than," indicating that the analyte concentration was above the certified upper reporting limit, which typically corresponds to the upper response range of the analytical instrument. The value reported is equal to the upper range. The reporting of a concentration as GT indicates that the sample was not diluted into the response range, likely due to either insufficient sample volume or due to holding

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time limitations. USAEC allows reporting of concentrations that are outside of the certified range but within acceptable limits. This is permitted when analyte recoveries exceed the upper limit of the certified range by less than 15 percent and the laboratory feels a dilution is not warranted. For this Phase II RI, 24 analyte concentrations for the VOC fraction (Methods LM23 and UM21) were reported as GT, but the concentration was higher than the 15 percent approved by the USAEC Chemistry Branch. For all of these 24 GT values, the laboratory calculated an estimated value based on instrument readings. Most of the ground water sample locations where these concentrations were observed were resampled and reanalyzed. In cases where resampling was not possible (soil samples), the estimated values were used.

2.6.3.3.2 Data Validation. Data validation is an integral part of this QA program. USAEC data validation was performed on 100 percent of all data packages by the DataChem QA Coordinator. This is internal laboratory data validation and is not equivalent to EPA Region I functional guidelines for data validation. Even though the primary responsibility for this review and validation rested with the laboratory performing the analyses, the Arthur D. Little Lead Chemist, or designee, was responsible for reviewing 10 percent of the data packages, following USAEC guidelines for data review, which are the same procedures followed by DataChem.

The following is brief outline of the data review and validation process:

- Evaluate for completeness of laboratory data.
- Evaluate data with respect to reporting limits.
- Evaluate data with respect to control limits.
- Review holding time data.
- Correlate laboratory data from related laboratory tests.
- Examine chain-of-custody records to ensure custody was properly maintained.
- Compare data on instrument print-outs with data recorded on worksheets or in notebooks.
- Check to ensure the same calibration was used for all samples within a lot.
- Examine chromatographic outputs and documentation of the reasons for manual integrations.
- Compare standard and sample preparation and injection records with instrument output to ensure each output is associated with the correct sample.
- Examine calibration and tuning results to ensure requirements are met.
- Check calculations on selected samples to ensure accuracy.
- Check that GC/MS library searches have been performed for all TICs, as required, and that results have been evaluated and recorded.
- Examine all papers and notebooks to ensure all pages are initialed, dated, and have sufficient explanation for changes, and that all items are legible.
- Compare transfer file, record, and group check results with analysis results.

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2.6.3.4 Data Reporting. The chemical results for samples analyzed for USAEC projects are entered into IRDMIS, the USAEC-provided software program, by DataChem. Data created using IRDMIS can then be electronically transmitted to Arthur D. Little's Data Manager or a diskette together with hardcopy printouts can be submitted.

All the subcontracted laboratory data are entered on a coding form by the analyst, which is verified by the peer checker and group leader/section manager. Laboratory QA personnel review data for obvious errors. These data are encoded onto a diskette, checked through two USAEC software routines, then printed out and verified by visual inspection by a Data Entry Specialist. Verified analytical results are then submitted to Arthur D. Little. DataChem retains a duplicate diskette of all data submitted.

All information pertaining to the analysis of a lot of samples is collected into a data package at the completion of analysis. The contents of data packages vary with methods of analysis, but generally include review sign-off sheets, field and laboratory chain-of-custody, chromatograms or instrument charts, all applicable laboratory logbooks, analysts' notebooks, calibration information, raw data, and example calculations. The package is reviewed by the laboratory QA personnel to eliminate technical errors that might affect the litigation quality of the data. The reported data are also reviewed by Data Entry for completeness before release.

DataChem subsequently sends all data packages to Arthur D. Little, where a final review is conducted of (10 percent of them). After the final review, all pertinent documentation in appropriately labeled boxes is delivered to USAEC.

2.6.3.5 Field Quality Control Samples. Various types of field QC samples are used to check the cleanliness and effectiveness of field handling methods. Field QC samples help indicate whether project data quality objectives have been met by providing quantitative and qualitative measures of precision, accuracy, representativeness, completeness, and comparability parameters. They are analyzed in the laboratory as samples, and their purpose is to assess the sampling and transport procedures as possible sources of sample contamination and to document overall sampling and analytical precision. Field staff may add blanks or duplicates if field circumstances are such that they consider normal procedures insufficient to prevent or control sample contamination, or at the direction of the Task Manager. Rigorous documentation of all field QC samples in the site logbooks is mandatory.

Field QC samples and the programmatic recommendations for frequency of collection are briefly described below. The specification and number of field QC samples to be collected are provided in the Quality Control Plan (ADL, 1993).

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2.6.3.5.1 Trip Blanks. Trip blanks are prepared at the laboratory prior to the sampling event by adding deionized water to a 40-ml VOC analysis vial containing two to three drops of concentrated hydrochloric acid; they are shipped with the sample bottles. One trip blank was used with every shipment of water samples for VOC or at a frequency of 1 per 20 samples, whichever was greater. Each trip blank was transported to the sampling location, handled in the same manner as a field sample (except the bottlecap was not removed), and returned to the laboratory for analysis without having been opened in the field. Trip blanks are not exposed to field conditions; results from the analysis of trip blanks are used to assess potential contamination from everything except ambient field conditions.

2.6.3.5.2 Field Equipment/Rinsate Blanks. Rinsate blanks are prepared on site by passing analyte-free water over sampling equipment; they are analyzed for all applicable parameters. The results of analyzing field equipment/rinsate blanks are used to document that sampling equipment have been properly prepared and cleaned before field use and that cleaning procedures between samples are sufficient to minimize cross contamination. If a sampling team is familiar with a particular site, it may be possible to predict the areas or samples that are likely to have the highest concentration of contaminants. The equipment blank samples collected at CRREL were taken after samples from high concentration areas were collected.

Equipment/rinsate blanks were collected through the ponar dredge sampler or hand auger for sediment samples, through a hand auger for surface soil samples, through a split spoon for subsurface soil samples, and through a bailer for ground water samples. Rinsate blanks are collected at a frequency of one per day or one per equipment type for each matrix, whichever is greater. Rinsate blanks were not collected for sampling activities that used dedicated equipment to collect each sample.

2.6.3.5.3 Field Duplicates. Field duplicates are two samples collected independently at a sampling location during a single sampling event. The results of analyzing field duplicates are used to assess the consistency of the overall sampling and analytical system. Field duplicate samples are generally collected at a rate of 1 per 20 or fewer samples per matrix. For BTEX and TPH sediment and soil samples, the field duplicate was collected from a homogeneous mixture of sediment or soil in a stainless steel bowl or on aluminum foil. For VOC sediment and soil samples, the duplicate was collected immediately after the initial VOC sample and was taken directly from the sampling medium. For ground water samples, the field duplicate was collected from the same bailer of ground water as the primary sample.

2.6.3.5.4 Field Blanks. Field blanks are exposed to field conditions by preparing the blanks at the sample collection site. Field blanks are collected at a rate of 1 per 20 field samples for each matrix.

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2.6.4 Analytical Data Quality Evaluation

In order to ensure that the environmental samples collected in support of the CRREL Phase II RI represent the actual conditions in the environment, the sampling program was designed to reduce analyte degradation, sampling variability, and cross contamination.

Precautions were taken to prevent alteration of sample constituents, beginning with the appropriate use of USAEC and EPA approved sample containers. Such precautions were necessary to prevent changes that can occur in some samples due to biodegradation from microorganisms, or the loss of volatile compounds with increasing temperature. Samples were iced and refrigerated, and chemical preservatives (HCl or HNO₃) were added to decrease volatility of organic compounds and control biological and chemical changes.

To reduce sampling variability we used standardized procedures specified in the QCP. This precaution helped us ensure that sampling was performed within the same guidelines each time. Sampling variability is measured by taking duplicate samples of the various types of environmental media. The precision of Arthur D. Little's sample collection and laboratory reproducibility is demonstrated when the analysis results for the duplicate samples are within acceptable limits.

The quality of the sample collection process is also evaluated by means of trip, field, and rinsate blanks. These sample blanks provide valuable data by monitoring the sampling process for cross contamination. Trip blanks are transported along with the empty sample containers being taken by the sampling team into the field. Field and rinsate blanks are used to assess contamination introduced in the field environment and by sampling equipment. When sampling is complete, the blanks are submitted along with the field samples for laboratory analyses. A brief description of the different types of QC samples and the information provided by each is provided in Section 2.6.3, Quality Assurance/Quality Control.

2.6.4.1 Quality Control Results. A QC review was performed for method blanks, field blanks, rinsate blanks, and trip blanks associated with the Phase II RI. This discussion is intended to provide an evaluation of data quality based on method blank and field QC data associated with all study areas.

Appendix K presents summary tables for all laboratory and field QC samples analyzed in support of the Phase II RI. The tables present results by analytical method and were used to identify any target analytes that appeared in the blanks. Also, they are arranged by QC Type (method blanks and rinsate blanks).

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2.6.4.1.1 Laboratory QC Samples. Method Blanks were analyzed at the laboratory with each lot of samples to evaluate if sample processing and analysis resulted in contamination of samples. Method blanks were performed on both water and soil samples. Results were reported for all the methodologies presented in Appendix K.

Volatile Organic Compounds (VOCs). Method blanks were run with each lot of water and soil samples to determine if VOCs were being introduced.

Thirteen method blanks were analyzed in association with VOCS in soil Method LM23. Only one compound was detected above the CRL, 1,1,1-trichloroethane, at 0.21 µg/g on a blank analyzed on September 1, 1993. This concentration is low enough to not represent a potential for cross contamination.

Water method blanks were also checked for VOC contamination by Method UM21. Twenty-one blanks were run at the laboratory. The following compounds were detected above the CRL: methylene chloride at 1.60 µg/L on a blank analyzed on October 6, 1993, 4-methyl-2-pentanone at 19.0 µg/L, and tetrachloroethane at 12.0 µg/L, both detected on one blank analyzed on September 3, 1993.

Naphthalene. Method blanks were analyzed to determine whether naphthalene was introduced during the sample preparation process. Water blanks were prepared using Method UM25.

Naphthalene was not detected above the corresponding CRL values in any of the water method blanks.

Benzene, Toluene Ethylbenzene and Xylene by GC. No BTEX were detected above corresponding CRL values in any of the water or soil blanks that were analyzed.

Total Petroleum Hydrocarbons by GC/FID. No TPH were detected above corresponding CRL values in any of the water or soil blanks that were analyzed.

2.6.4.1.2 Field QC Samples. QC samples were collected in the field to assess overall precision, accuracy and representativeness of the sampling and analytical efforts. The number of QC samples collected for this effort is based on the total number of field samples as established in the QCP. All results for these samples are presented in Appendix K and interpretation of them is summarized as follows.

Trip Blanks. A total of 41 trip blanks were submitted for VOC analysis. Twelve of the trip blanks contained reportable concentrations of contaminants. Seven of the trip blanks submitted during the period of September 30 through December 2, 1993, contained low levels of TCE (1.40 to 4.10 µg/L). TCE was one of the compounds of concern and it was observed at high concentrations in samples contained in the

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coolers that accompanied these trip blanks; conceivably, these samples contributed to these concentration levels. Toluene was also observed at low concentrations (1.30 and 1.50 µg/L), collected on July 22 and 27, 1993, probably due to high concentrations present in samples contained in the cooler. Three of these trip blanks, submitted on September 28 and 29, 1993, contained low concentrations (1.70 to 2.10 µg/L) of methylene chloride.

Trichlorofluoromethane was found in the August 27, 1993 blank at 1.20 µg/L. The presence of these two compounds is likely due to laboratory contamination and is not a major concern. In addition, three blanks collected on August 20 through 27, 1993 had tentatively identified cyclic aromatic compounds at concentrations ranging from 5 to 50 µg/L. Overall, the trip blank contaminants were very few, relatively uniform, and at very low concentrations, not at all unexpected.

Rinsate Blanks. A total of 33 rinsate samples were collected for the Phase II RI, at a rate of 5 per week, ensuring that rinsate blanks were collected for all equipment used for all matrices in this program (i.e., soils, sediments, surface water, and ground water). Most of the contaminants found in the rinsate blanks are attributable to background laboratory contamination. For example, acetone, found in two of the rinsate blanks analyzed on October 1 and November 30, 1993, at levels of 21 and 32 µg/L respectively; and chloroform, found in the blank collected on June 24, 1993, at a concentration of 1.4 µg/L, were probably due to the water used for rinsing. Toluene and TCE were found at very low concentrations (1.60 and 2.20 µg/L) in the blanks collected on August 26 and November 30, 1993. A high concentration of TPH-diesel (150 µg/L) was observed in the blank collected on September 29, 1993. These three compounds were observed at high concentrations in the samples collected on the same days as the blanks. The source of these contaminants was investigated. Two likely sources are the de-ionization process of the water provided by the laboratory and the decontamination process in the field. It is very difficult to achieve complete equipment decontamination without the use of solvents, as evidenced by the results of the rinsate blanks. In order to safeguard against potential cross contamination, the sampling staff implemented the practice of doing a second decontamination of the equipment before sampling the next location. This procedure minimizes the possibility of crosscontamination.

Field Blanks. Of the 11 field blanks collected, three had detectable concentrations of contaminants ranging from 1.1 to 24 µg/L. Chloroform was detected in the blanks collected on June 24 and December 1, 1993. Because chloroform was detected in rinsate blanks, the DI water provided by the laboratory is the most likely source of this contaminant. Acetone was detected in the blank collected on December 1, 1993, however, the presence of this compound is likely due to laboratory contamination and is not a major concern. The blank collected on October 1, 1993, presented reportable concentrations of the following compounds: 1,1,1-trichloroethane at 1.4 µg/L,

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m-xylene at 1.6 µg/L, benzene at 1.9 µg/L, and toluene at 5.8 µg/L. These four compounds were observed at high concentrations in the samples collected on the same day as this blank, therefore, we estimate that there was a cross contamination potential.

Duplicates. Field duplicate samples were collected at a rate of 1 per 20 field samples. Duplicates are differentiated from samples in the identification code. The duplicate code is identical to the conjugate sample code except that the third digit in the duplicate code is a "D". Overall, the duplicate samples indicate acceptable precision for both water and soil samples. A summary of duplicate data is presented in Appendix K.

2.6.4.2 Data Quality Evaluation. Upon evaluation of the results of the field and QC samples we have concluded that the results for the data quality objectives (DQOs) given in the QCP for the data quality indicators (precision, accuracy, representativeness, completeness, and comparability) provide evidence that the program's DQOs were achieved.

Precision - The analytical results of the field duplicates provided precision information for the assessment of the variability associated with field activities, which is a function of sample collection/handling as well as matrix homogeneity. All 17 field duplicates indicated acceptable precision for both water and soil samples.

Accuracy - This indicator was assessed as part of the USAEC control chart program. These charts, which are maintained for each control analyte by plotting the recovery of spiked QC samples, monitored the variations in the accuracy of routine analyses and detected trends in the observed variations. Based on our data validation results and the acceptance letters of the USAEC Chemistry Branch, the data generated to support this study met the QCP accuracy objectives.

Representativeness - All sampling locations for the Phase II RI were selected using a targeted sampling design. Representativeness reflects this design and is maximized by proper selection of sampling locations and collection of a sufficient number of samples. The Work Plan provides a very exhaustive description of why samples were selected.

Completeness - There was some loss of data due to laboratory instrument failure and the reporting of several data points as "GT" rather than diluting and reanalyzing the sample. As discussed in Section 2.6.3.3.1, for this Phase II RI, 24 analyte concentrations for the VOC fraction (Methods LM23 and UM21) were reported as GT. The samples where these concentrations were observed were resampled and reanalyzed. In cases where resampling was not possible, the estimated values were used. In addition, 99 out of 194 field and QC samples (51 percent) analyzed for

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TPH-GC/FID, failed to meet holding times. The TPH values for these samples will be used as estimated. However, the goal of 90 percent completeness was met and exceeded; 99 percent completeness was achieved.

Comparability - In order to increase the level of confidence with which this data set can be compared to another, we ensured that our field team and laboratory were using the appropriate sampling methods, chain-of-custody procedures, USAEC and EPA methods, adherence to QA/QC program, units of reporting, and correction of measured values to standard conditions.

USAEC Data Validation. As specified in the CRREL QCP, the commander of the USAEC is ultimately responsible for the quality of data collected in support of Agency projects. This responsibility is delegated to the Chemistry Branch and individual Project Officers/Project Chemists. The Chemistry Branch is responsible for maintaining an active, ongoing system of QA/QC. A critical role of the Chemistry Branch is to evaluate the quality of data generated by Contractor Laboratories -- DataChem Laboratories in this case. In addition, this branch monitored the effective implementation of QA/QC at DataChem and reported these observations to the Commander of USAEC and to Arthur D. Little.

An important tool employed by the Chemistry Branch to evaluate the quality of data generated by Contractor Laboratories is the use of control charts. Basically, this technique indicates when a measurements process that was in statistical control has moved out of statistical control. In other words, it indicates that the measurement process has not shifted, as would happen if a new standard were prepared incorrectly, nor has the degree of variability shifted, such as might occur if an untrained analyst were to perform the determination. The control charts are transmitted to USAEC and Arthur D. Little weekly. The control charts are reviewed by the laboratory coordinator, analytical task manager, and laboratory QA staff before any data are transmitted to USAEC IRDMIS data files. This process is very sensitive, which is why both the Arthur D. Little Project Chemist and the Chemistry Branch performed an exhaustive review of all control charts generated by DataChem. When out of control situations were detected, they were investigated and corrected. No data were rejected due to poor performance.

In order to monitor the QA/QC activities of the laboratory to ensure conformance with authorized policies, procedures, and sound practices, Arthur D. Little conducted one laboratory audit and one site visit. A comprehensive laboratory audit was performed on September 13 through 14, 1993; the Sample Receiving Area, the Organic Preparation, the Volatile organic Analysis, and the Semivolatile Organic Analysis laboratories were perceived as areas potentially in need of improvement. The site visit was conducted on December 14, 1993, with the participation of the TEPS Program Manager, a Project Manager, and a Project Chemist. The focus of these

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activities was to discuss with laboratory personnel the circumstances that affected their ability to meet the milestones stipulated in the contract, and the data quality deficiencies observed during the last quarter of 1993. The specific issues addressed in these audits are presented in Appendix K.

Arthur D. Little's Data Validation. As we specified in the QCP, 10 percent of the data generated in this study was validated using the USAEC guidelines presented in the USATHAMA QAP (1990). The packages were chosen to cover a broad range of analyses and matrices. The Arthur D. Little Chemistry Group assessed these packages for completeness of the documentation provided, adherence to the analytical methods, adherence to the USAEC QC requirements, and acceptability of QC data. They also provided a technical review of the data and verification of the calculation procedures. A form similar to that contained in Appendix T of the 1990 USAEC Quality Assurance Program was used by the validators to present their results.

The validation process for the data generated to support the Phase II RI demonstrated that the program met the DQOs. No major deviations or problems were noted. Some observations were made by our validators that revealed a need for the laboratory to improve their documentation practices and to provide necessary raw data to reproduce their calculations. Raw data for daily calibration and acceptance criteria were missing from several data packages. Errors were also noted in entry of dates on the IRDMIS. Some discrepancies were also noted between flagging codes recommended in acceptance letters and those noted on the IRDMIS printout contained in the data package. The Quality Assurance Status Report, which discusses control chart results, was also missing from data packages. However, none of these occurrences were significant enough to jeopardize the integrity of the data. In addition, these issues were presented to the laboratory and appropriate corrective actions were taken and were fully documented to avoid reoccurrence.

2.7 Investigation-Derived Waste

Investigation-derived waste is any waste generated during the implementation of the field investigation. This waste may include drilling fluids, drill cuttings, decontamination fluids, development water, and purge water. All waste generated at CRREL was containerized in 55-gallon DOT-approved drums at the area of collection.

The containerized material was field screened to determine if it should be treated as potentially hazardous material. A sample of the waste was placed in a one-half pint jar. The mouth of the jar was covered with aluminum foil and capped with the jar's lid. After agitation, the lid was removed and the tip of the Microtip PID indicator was inserted through the foil cover into the sample's headspace. The headspace of the

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material was documented in a logbook and on the 55-gallon drum. If the headspace was less than 5 ppm, then material was considered to be non-hazardous waste. If the headspace was greater than 5 ppm, then the material was considered to be potentially hazardous.

Nonhazardous waste was disposed of at locations designated by the CRREL facilities engineer. Nonhazardous drilling fluid waste and decontamination water was disposed of at the southern end of CRREL pond. Nonhazardous native soil was disposed of at the northeastern end of CRREL pond. Nonhazardous well development water and purge water was allowed to infiltrate back into the ground near the point of removal.

Material that was considered to be potentially hazardous was contained in 55-gallon drums, labeled, and temporarily stored at a fenced concrete storage area near the northwest boundary of CRREL. Each drum was labeled with the site location ID, sample date, PID screen results, and media type. At the end of the drilling and soil boring program, a total of 115 drums contained potentially hazardous waste. For the purpose of sampling, the drums were placed into one of 25 groups based on similar location, media type, and screening results. Each drum was sampled individually and composited, based on the group designations, by the contract laboratory. All composites were analyzed for toxicity characteristic leaching procedure (TCLP) VOCs to determine if leachable hazardous constituents were present. In addition, composite samples from the three groups of drums containing the highest PID screening values were analyzed for the full suite of TCLP analytes (metals, semivolatiles, PCBs, and pesticides).

Appendix L presents TCLP results for the investigative-derived waste. Based on these results, the waste is classified as nonhazardous as specified by the criteria listed in 40 CFR 261. The waste was disposed of at an on-site location designated by authorized CRREL personnel. This task was performed by Clean Harbors, Inc., of Hooksett, New Hampshire, under the supervision of Arthur D. Little.

No hazardous waste was generated during this investigation.

2.8 Decontamination Procedures

All non-disposable invasive and chemical sampling equipment was decontaminated prior to and after use at each drilling or sampling location. The following is a description of the specific methodology used for decontamination.

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Drilling and Borehole Geophysical Survey Equipment

All drilling and borehole geophysical survey equipment (drill rig, augers, core barrels, drilling assembly, and geophysical instruments) were decontaminated at the decontamination pad located near the Ice Engineering Facility's loading dock. Decontamination consisted of steam-cleaning the equipment until the equipment was visibly clean. Water used for steam cleaning originated from well CECRL03, which was certified as a suitable source (i.e., free of VOCs) prior to the field investigation. Spent water was retained on the decontamination pad and pumped to 55-gallon drums.

Soil/Sediment Sampling Equipment

All soil sampling equipment (split spoons, hand augers, dredges, and stainless steel trowels, spoons, and bowls) were decontaminated between each soil sample. The decontamination procedure consisted of three steps. First, all dirty equipment was scrubbed in a 5-gallon bucket until visibly clean. A second scrub was then given in another 5-gallon bucket. Water used for both scrubs was derived from well CECRL03. The third step consisted of a thorough rinse using commercially available distilled water. All equipment was allowed to air dry.

Ground Water Sampling Equipment

All ground water sampling equipment (pumps, hose, and bailers) were decontaminated between each well. The pumps and hose were decontaminated by passing clean water through the equipment and by a thorough wiping of the exterior of the equipment. This was accomplished by setting up two 55-gallon drums -- one filled with water from well CECRL03, and one empty. The pump was placed in the clean water and the discharge hose was placed in the empty drum. The pump operated until approximately 25 gallons had passed through the hose. The bailers were decontaminated by scrubbing vigorously with commercially available distilled water.

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3.0 Physical Characteristics of the Study Area

This section presents the physical characteristics of CRREL and vicinity. The purpose of this section is to establish the basis for a conceptual site model to explain the distribution of known site contaminants and their potential for continued migration.

3.1 Surface Features

CRREL is located in the upper Connecticut River Valley on terraced unconsolidated glacial deposits. Despite modification of the topography by development, CRREL has three main terraces at elevations ranging from 520 feet to 460 feet above mean sea level (msl). The eastern third of CRREL is located on the upper terrace and contains AOCs 1, 2, 3, 4, 5, 9, and 14. The upper terrace slopes gently down to the west. The middle terrace is very narrow (generally less than 100 feet) and covered by asphalt. It contains AOCs 6, 7, 8, and 13. At 460 feet above msl, the lower terrace is very flat and extends westward to the western border of CRREL. The lower terrace contains AOCs 10, 11, 12, 15, and 16. A steep escarpment drops approximately 80 feet to the Connecticut River 50 to 150 feet west of the CRREL property line (Figure 2-1).

Most of CRREL is covered by either buildings or pavement. The Child Care Center, the Main Laboratory building, the Facility Engineering building, and the Logistics and Supply building are located on the upper terrace. Aside from two storage buildings, the middle terrace is covered by an access road and parking lots. The CRREL greenhouse, the FERF, the Geophysical Research Facility, the Ground Water Treatment Facility, and storage yard are maintained on the lower terrace. The lower terrace also contains five production wells (CECRL01 through CECRL05).

The only body of surface water at CRREL is a small pond located in the extreme southern end of the lower terrace. The pond is approximately 100 feet by 50 feet. In the late 1980s, the pond was constructed to serve as a holding area for urea water utilized by the Ice Engineering Facility in testing of a sea ice model. In order to contain the materials placed in the pond, a clay liner was constructed and a clay berm was built along the southern boundary to dam the remnants of a stream that once flowed along the lower terrace. Soon after the pond's construction, however, the urea discharge was discontinued and the only input to the pond was derived from site runoff. After the spring floods each year, approximately 100,000 gallons of this runoff mixture is pumped from the pond and discharged into the Connecticut River via the storm drain system. This process continues to be used to control the water level in the pond.

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3.2 Climate

The climate in the vicinity of CRREL is characterized as humid and continental, with four distinct seasons and fairly extreme temperatures. The variable conditions are caused by the influence of marine and continental air flows, from polar and tropical air masses. The prevailing wind direction and annual mean wind speed is southeast at 7 miles per hour (U.S. Department of Commerce, 1979). As measured by the Hanover meteorological station, the 30-year mean monthly temperature ranges from 18.2°F (January) to 69.5°F (July), with an annual mean temperature of 44.9°F (National Climatic Center, 1983).

The normal annual precipitation is 36.67 inches, with 2.74 inches occurring during the month of January and 3.3 inches occurring during the month of July (National Climatic Center, 1983). The 2-year, 24-hour rainfall record is 2.5 inches (U.S. Department of Commerce, undated). The mean annual total snowfall is 80 inches.

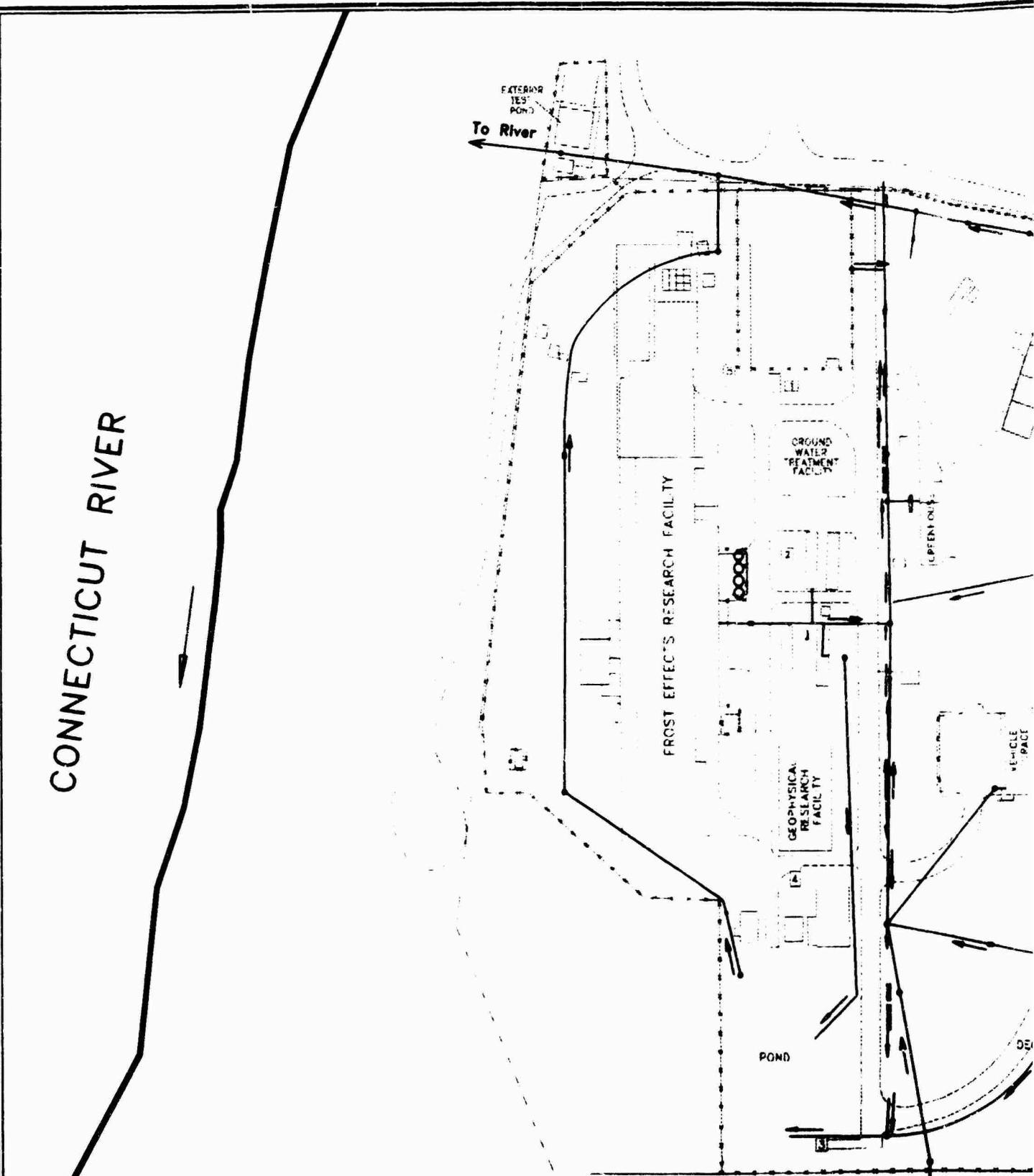
3.3 Surface Water Hydrology

The Connecticut River drainage basin encompasses an area of 4,092 square miles, with a discharge that ranges from 82 ft³/sec to 136,000 ft³/sec. At the West Lebanon gauging station, located 5.6 miles downstream of CRREL and below the point of confluence with the White River, the average discharge of the river is calculated at 7,121 ft³/sec (Blakey et al., 1989). The average discharge at a location approximately 5 miles upstream of CRREL is estimated to be 4,900 ft³/sec (Hodges, et al., 1976).

The water level of the Connecticut River near CRREL is controlled by the New England Power Company dam at Wilder, Vermont. The dam is located 4.5 miles downstream of CRREL. The reservoir produced by the dam extends 30 miles upstream to the Piermont-Haverhill, New Hampshire area. The normal residence time of water in the reservoir ranges from two to five days, depending on discharge rates at the dam. Under New England Power Company's operating permit, the reservoir elevation is maintained between 380 and 385 feet above msl. The water level in the reservoir normally does not fluctuate more than 1 foot a day, with drawdown occurring during peak power usage (Wehran, 1991).

Surface water drainage at CRREL is generally from east to west. Most of the surface water runoff is collected by CRREL's storm sewer system (Figure 3-1). This system is augmented by drainage culverts and swales. However, in the vicinity of production well CECRL03, drainage is to the south in a ravine that runs parallel to the east side of the esker ridge (EPIC, 1991). The storm sewer system also handles spent refrigeration and cooling water from the various engineering laboratories. This water originates from the production wells (CECRL01 through CECRL05) on the lower

CONNECTICUT RIVER



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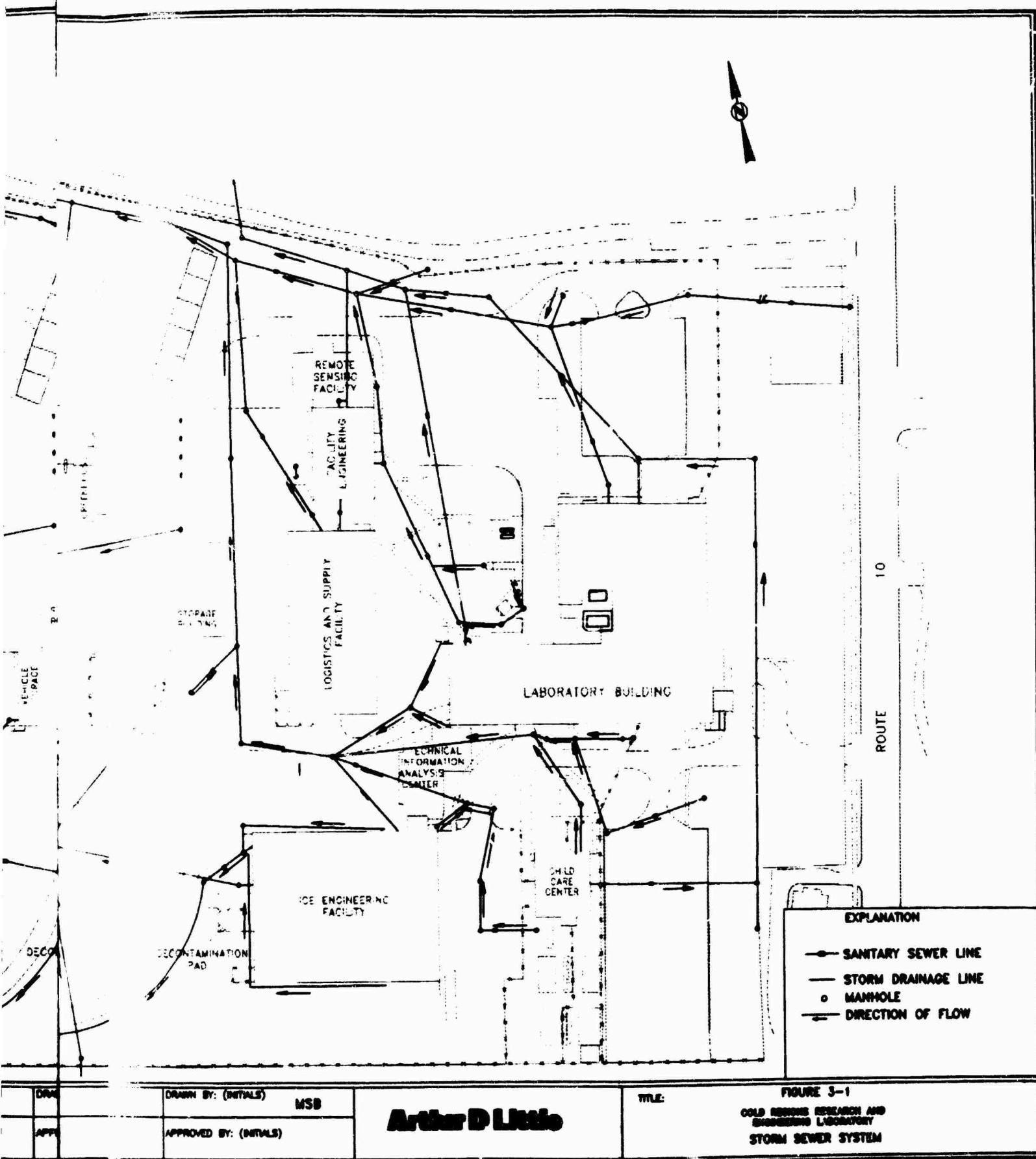
DATE:
FEB., 1993

SCALE:



DWG. NO.

67063-045



CRREL: RI Report
Section No.: 3.0
Revision No.: 1
Date: March 18, 1994

terrace. The vast majority of storm water and all of the production water is ultimately discharged, through the CRREL storm sewer system, to the Connecticut River via a single outfall. CRREL has estimated that, on average, 365 million gallons of cooling water and 23 million gallons of storm water are discharged through the storm sewer system to the Connecticut River on a yearly basis. All other waste water is discharged to the municipal sewer system operated by the Hanover Water Company.

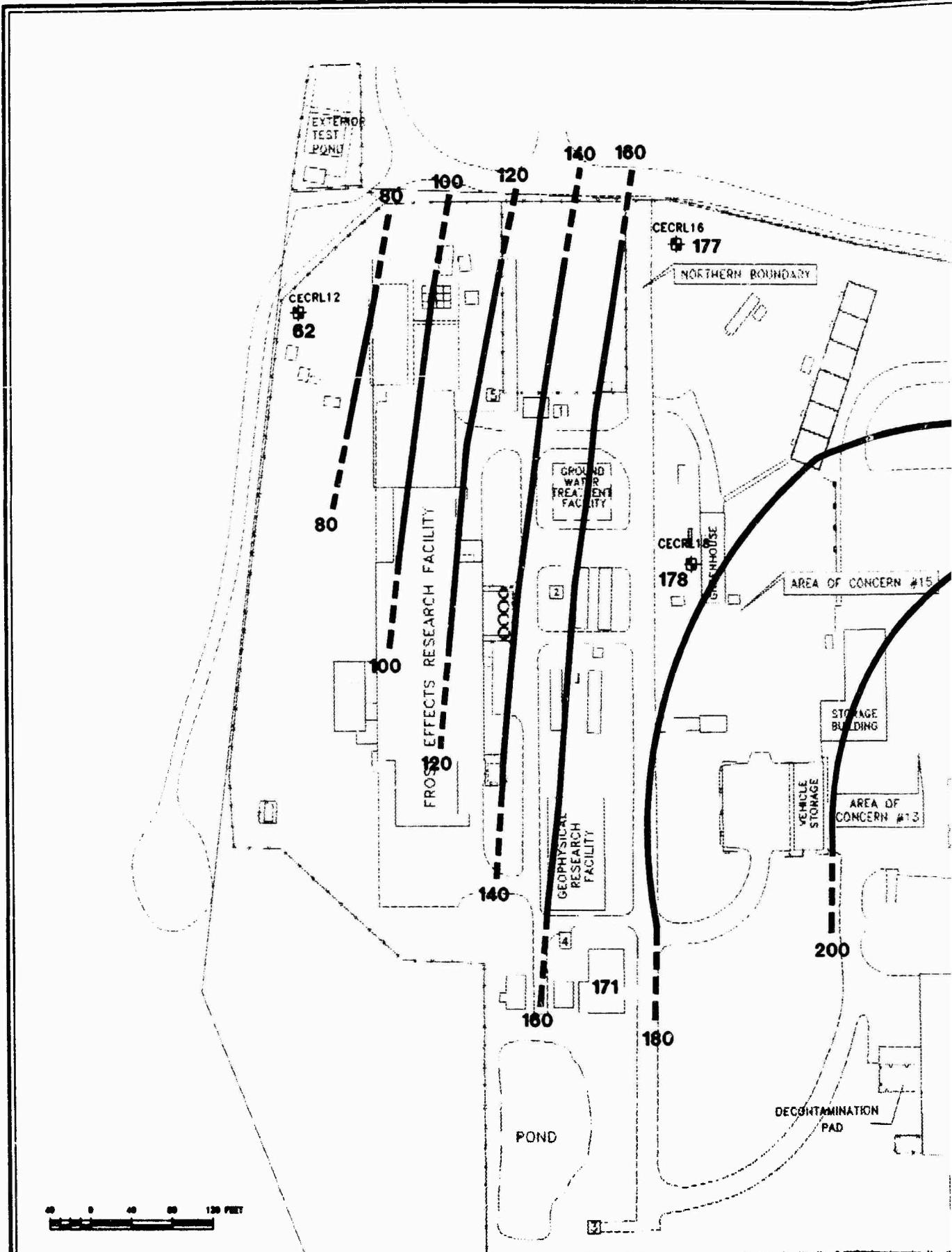
As previously mentioned, the only body of surface water on CRREL is a small pond located at the southern end of the lower terrace near production well CECRL03. This is an artificial pond, built to limit surface water runoff to the south. The pond receives surface water runoff and water from the Ice Engineering building. Water from this pond is periodically pumped to the Connecticut River via the storm sewer system.

3.4 Geology

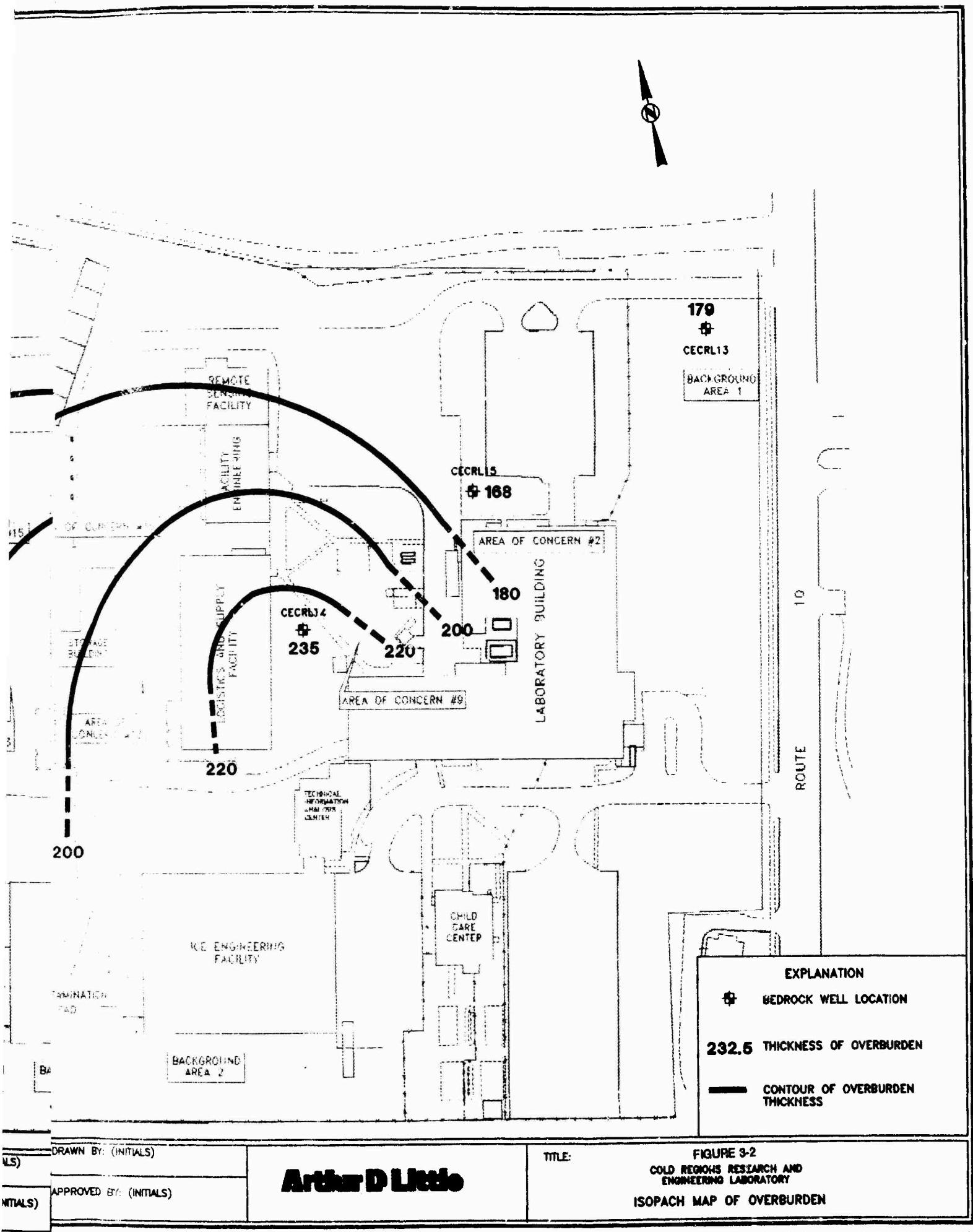
This section describes aspects of the geology of CRREL and vicinity that may be important to determining routes of contaminant migration both to off-site receptors and between various CRREL AOCs. Information used for this site-specific geologic description and interpretation is derived from boring logs from boreholes and wells drilled as part of this remedial investigation and previous CRREL engineering activities (including those related to the construction of the FERF and supply wells), as well as several geophysical surveys and bedrock coring activities previously described in Section 2.0. Geologic information used for the general study area across the river in Vermont is derived from previous investigations. General geologic background information, including information on the regional geologic setting, is derived from a synthesis of academic papers.

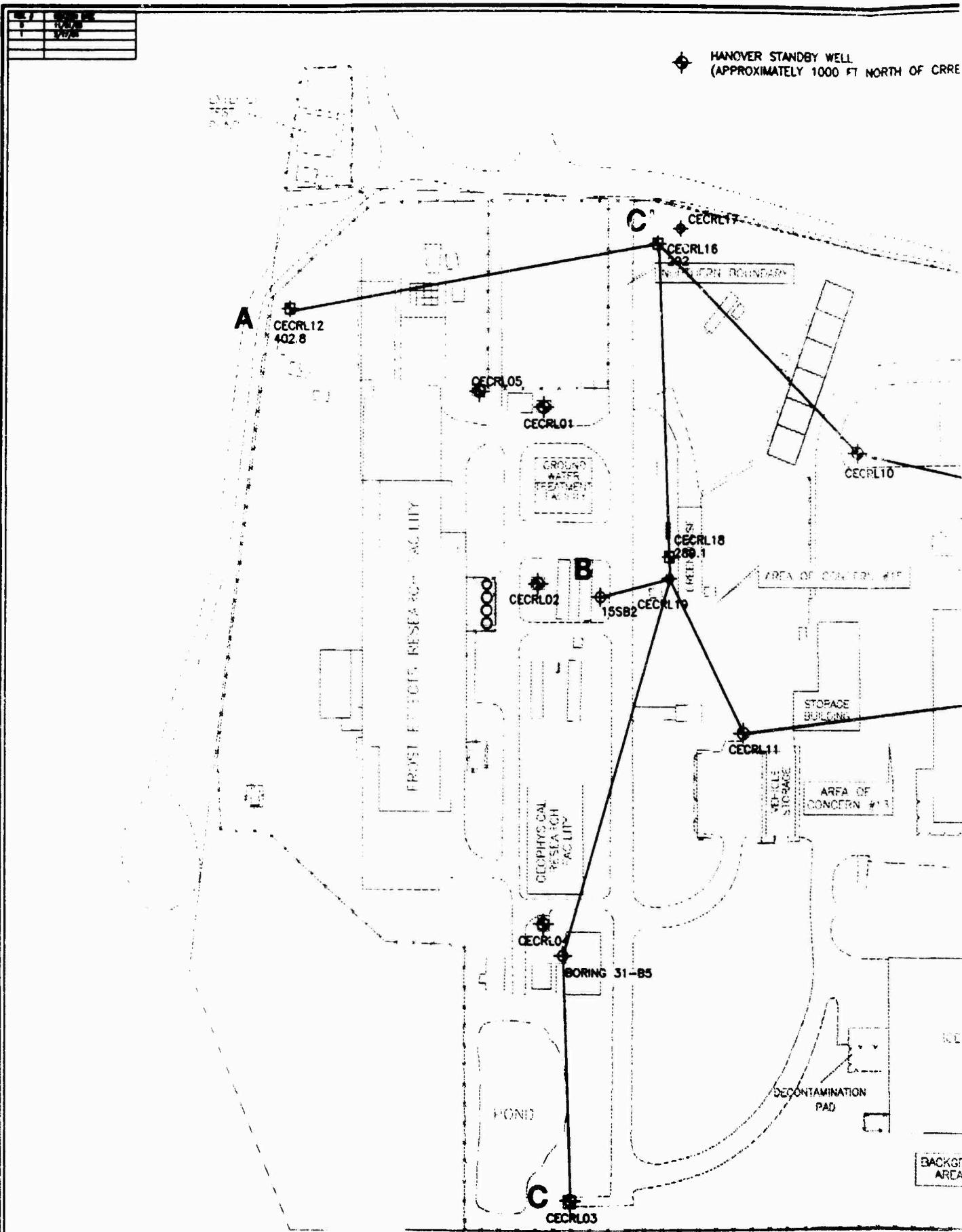
The geology of CRREL consists of two main geologic units -- the overburden sequence and the bedrock. The overburden consists entirely of glaciofluvial and glaciolacustrine sediments. Figure 3-2 is an isopach map of the overburden thickness. The bedrock consists of poly-deformed metasedimentary rock. Figures 3-3 to 3-6 are geologic cross sections across CRREL and vicinity. These cross sections are based on logs from wells and soil borings, and geophysical data collected during the RI field investigation.

The general study area outside of CRREL includes the Connecticut River and a portion of Norwich, Vermont, adjacent the river. Figure 3-7 is a geologic cross-section and plan view map of the general study area. This portion of the cross section, west of the Connecticut River, is based on information provided from two ground water investigation reports (Wehran, 1991 and The Johnson Co., 1993) under the authority of the VTDEC.



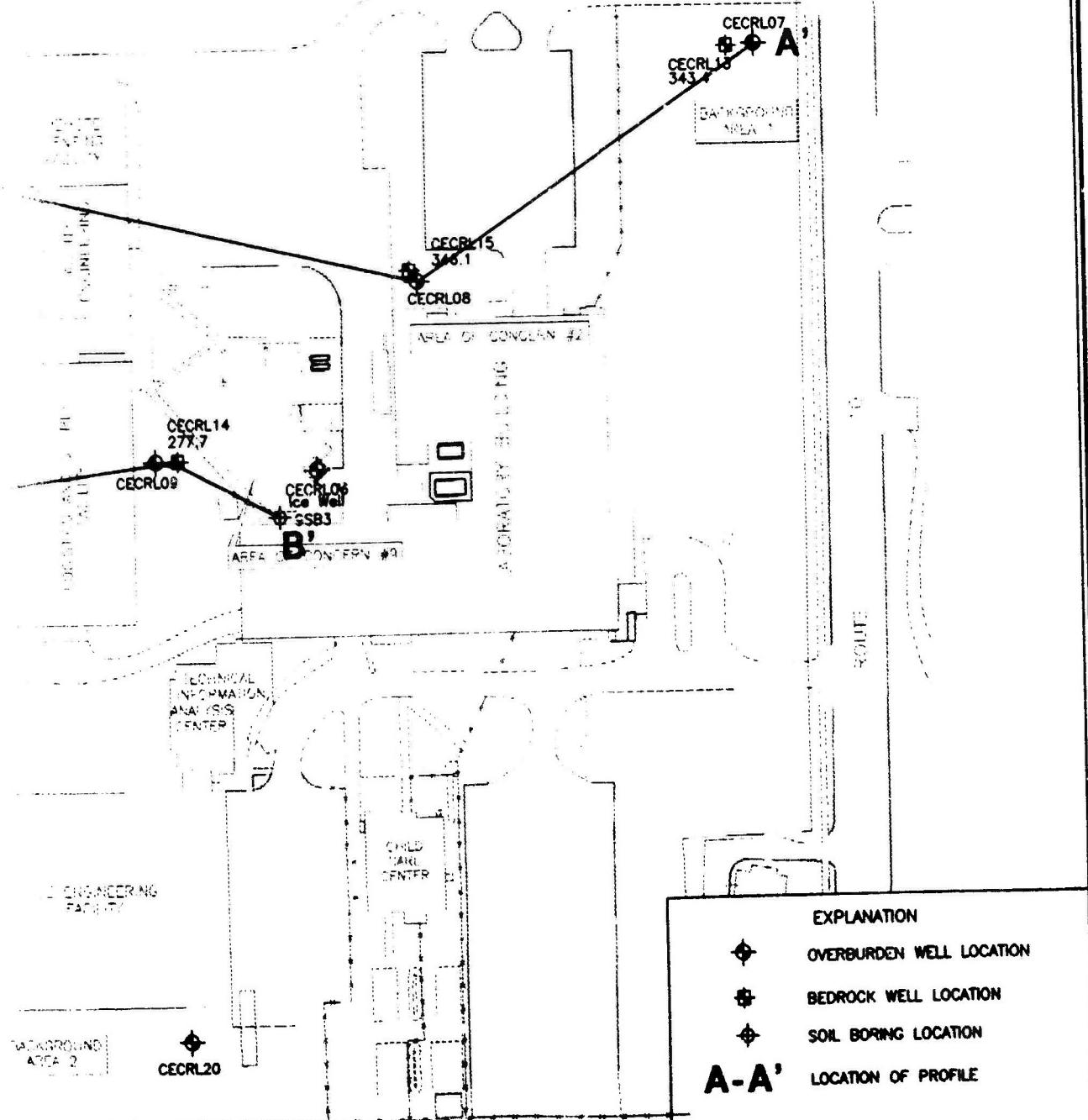
PREPARED FOR: USAEC		DRAWN BY: (INITIALS)
DATE: FEB. 1994	SCALE: AS SHOWN	DWG. NO. 67063-059
		APPROVED BY: (INITIALS)





PREPARED FOR:	USAEC	DRAWN BY: (INITIALS)
DATE:	SCALE:	MIS
DEC. 1993	100 FEET	DWG. NO. 67063-036

CRRE ELL
(FT NORTH OF BARREL)



MS BY: (INITIALS)

MSB

ED BY: (INITIALS)

Arthur D Little

TITLE:

FIGURE 3-3
COLD REGIONS RESEARCH AND
ENGINEERING LABORATORY
LOCATIONS OF CROSS SECTIONS A-A' TO C-C'

070301TEPS/report_1_sp.0017004

REV. #	REVISION DATE
0	1/7/84
1	3/12/84

WEST

A
FT (AMSL)

550
500
450

CECRL12

CECRL16/17

CECRL10

400
350
300
250

SP/SW

ESKER

BEDROCK

CL
C
E
K=3.50E-05
K=3.67E-07

SM

K=1.40E-05

VERTICAL EXAGGERATION = 1.13X

HORIZONTAL SCALE

0 200 FT.

PREPARED FOR:

USAEC

DRAWN BY: (INITIALS)
MSB

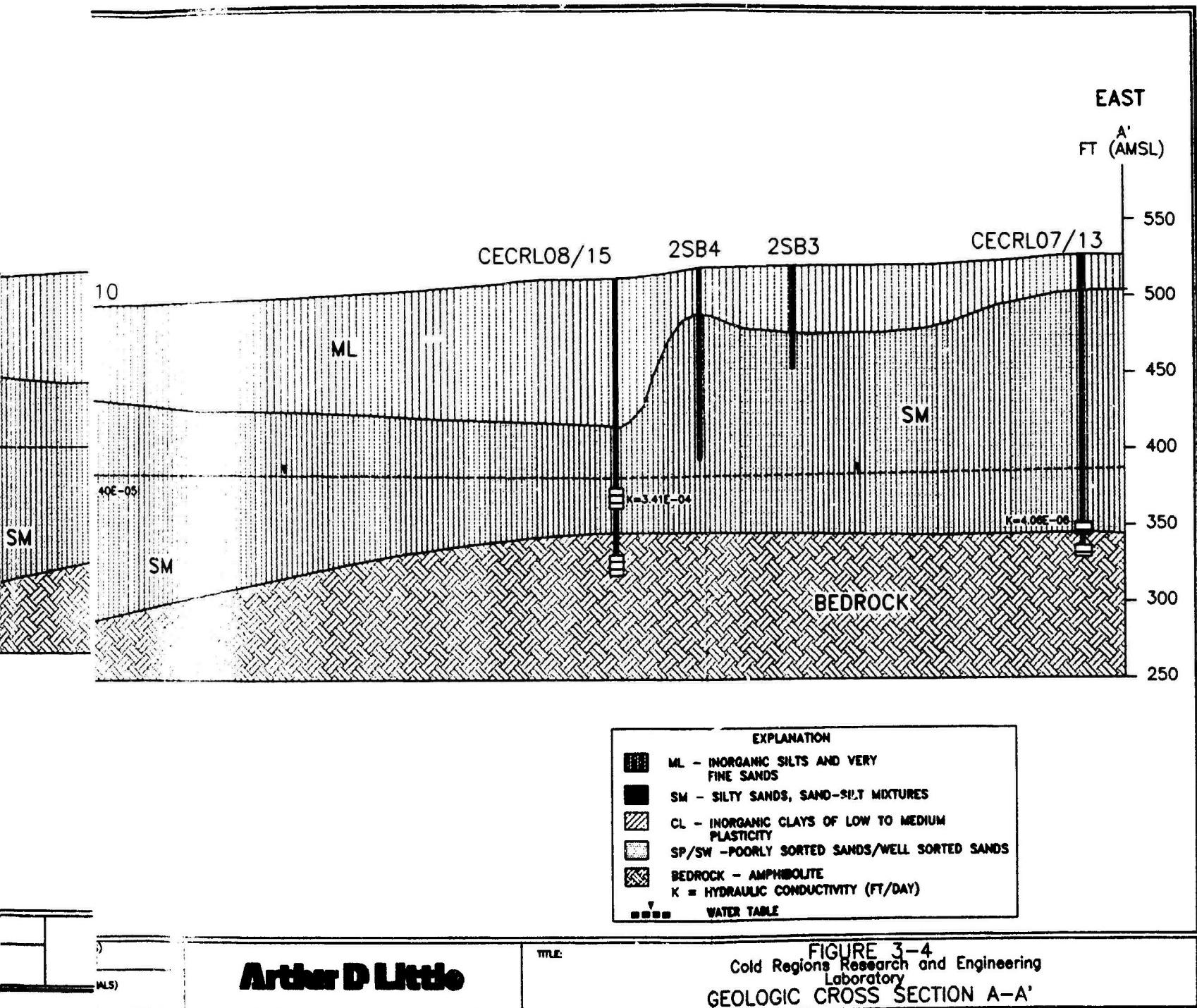
DATE:
MAR. 1994

SCALE:

AS SHOWN

DRG. NO.
67063-027

APPROVED BY: (INITIALS)



REV. #	REVISION DATE
0	1/10/94
1	3/12/94

WEST

B

FT(AMSL)

500

15SB2

CECRL18/19

450

CL

400

ESKER
SP/SW

350

$K=2.62E-06$

300

SM

250

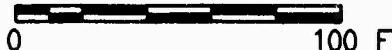
$K=1.72E-07$

CECRL11

$K=1.46E-06$

BEDROCK

HORIZONTAL SCALE



VERTICAL EXAGGERATION

PREPARED FOR:

USAEC

DRAWN BY:

M

DATE:

MAR. 1994

SCALE:

AS SHOWN

DWG. NO.

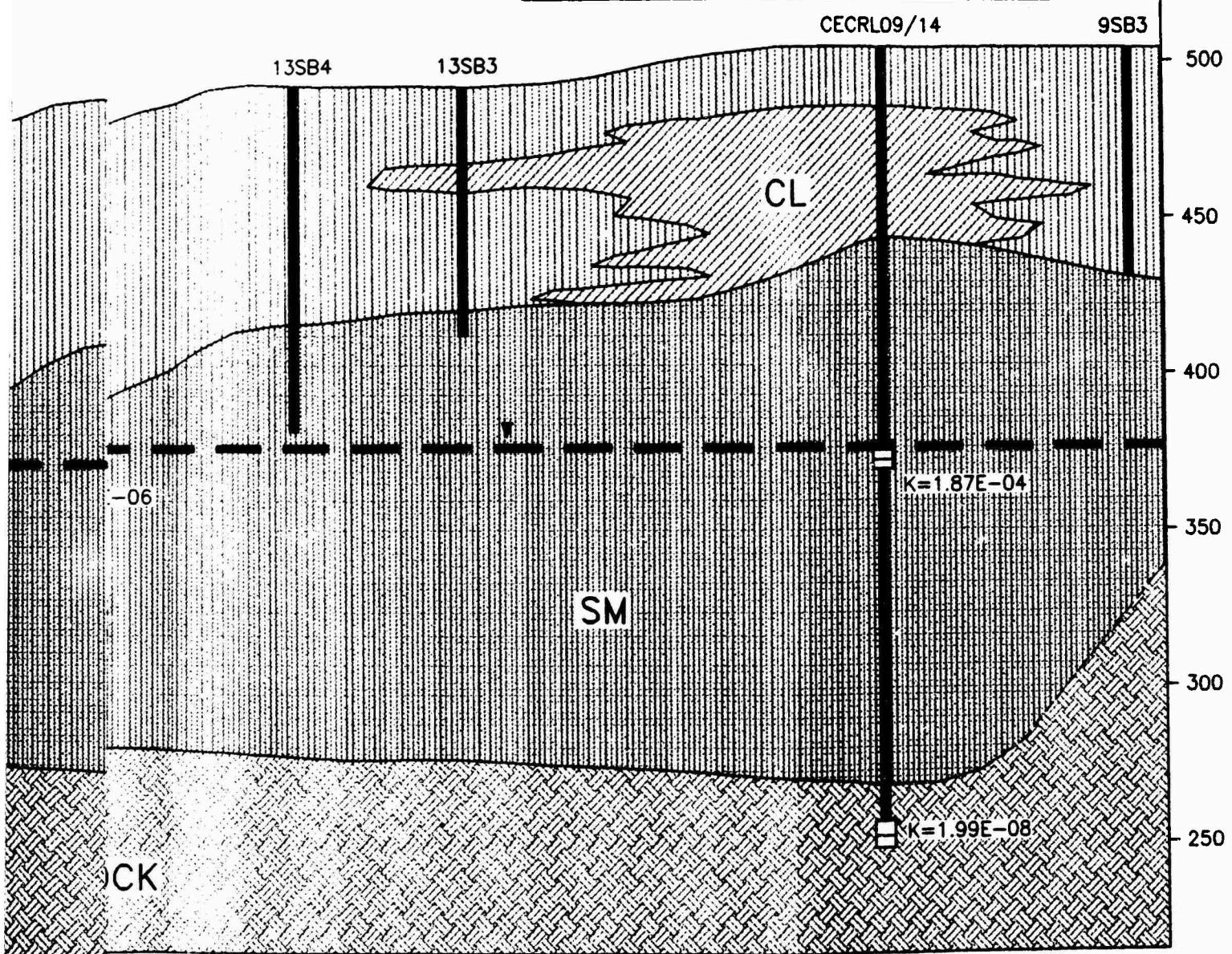
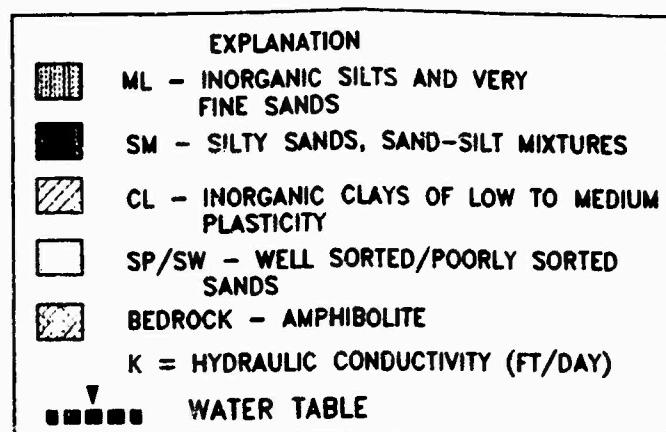
67063-022

APPROVED BY:

EAST

B'

FT(AMSL)



WN BY: MSB/TG
MSB/TG
ROVED BY:

Arthur D Little

TITLE:

FIGURE 3-5
Cold Regions Research and Engineering
Laboratory
Geologic Cross Section B-B'

670801TEP8.report.d rpt.bdt.03/17/84

3-8

REV. #	REVISION DATE
0	1/7/94
1	3/14/94

SOUTH

C

FEET (AMSL)

500

CECRL03

SB31-05

460

ML

420

380

340

SM

300

SP/SW

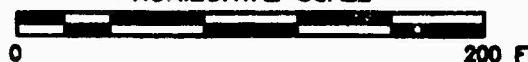
ESKER

260

BEDROCK

220

HORIZONTAL SCALE



VERTICAL EXAGGERATION = 1.17X

PREPARED FOR:

USAEC

DRAWN BY: (INITIALS)

DATE:

MAR. 1994

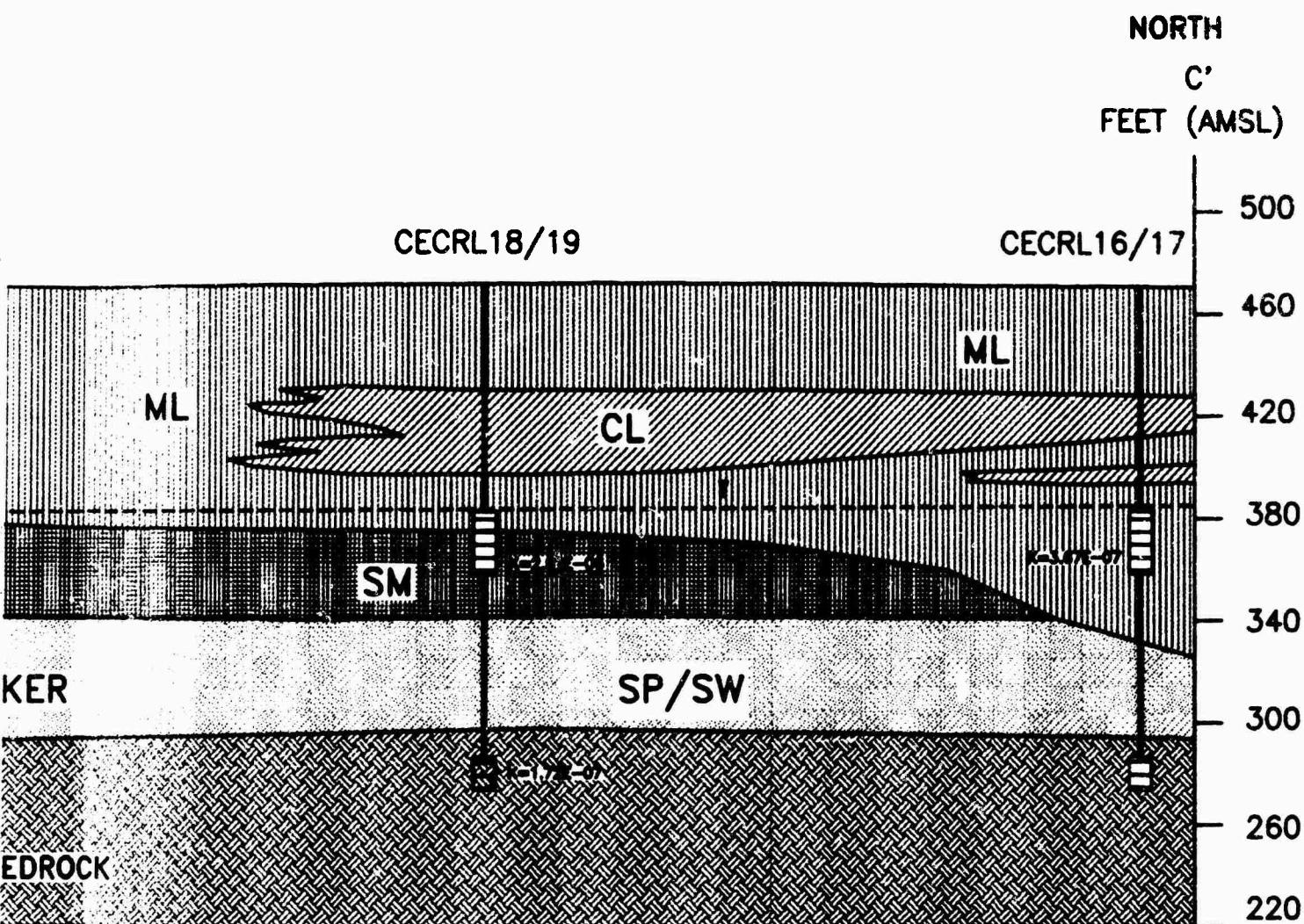
SCALE:

AS SHOWN

DWG. NO.

67043-017

APPROVED BY: (INITIALS)



EXPLANATION

- ML - INORGANIC SILTS AND VERY FINE SANDS
- SM - SILTY SANDS, SAND-SILT MIXTURES
- CL - INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY
- SP/SW - POORLY SORTED SANDS/WELL SORTED SANDS
- BEDROCK - AMPHIBOLITE
- K = HYDRAULIC CONDUCTIVITY (FT/DAY)
- WATER TABLE

Y: (INITIALS)

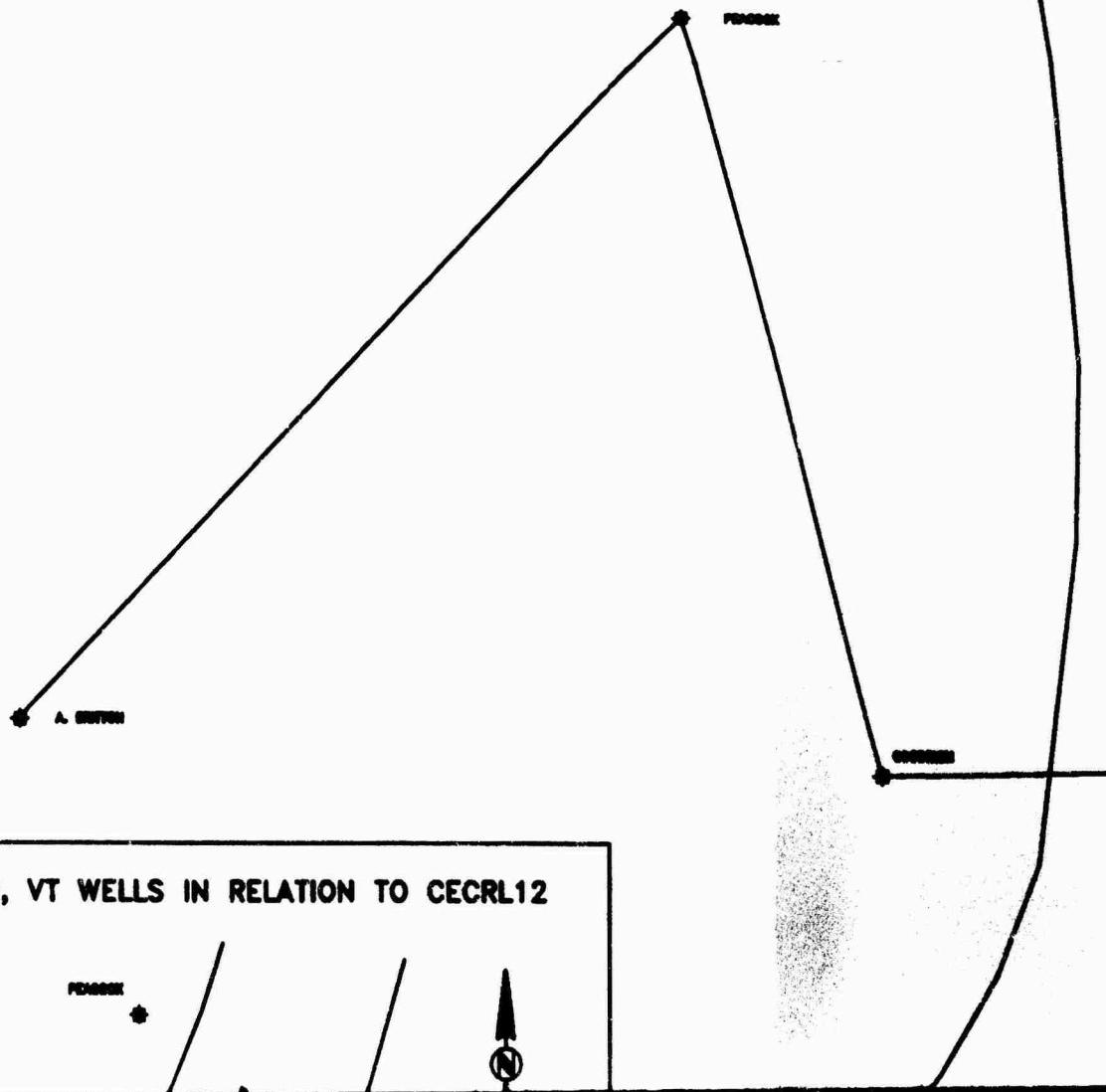
D BY: (INITIALS)

Arthur D Little

TITLE:

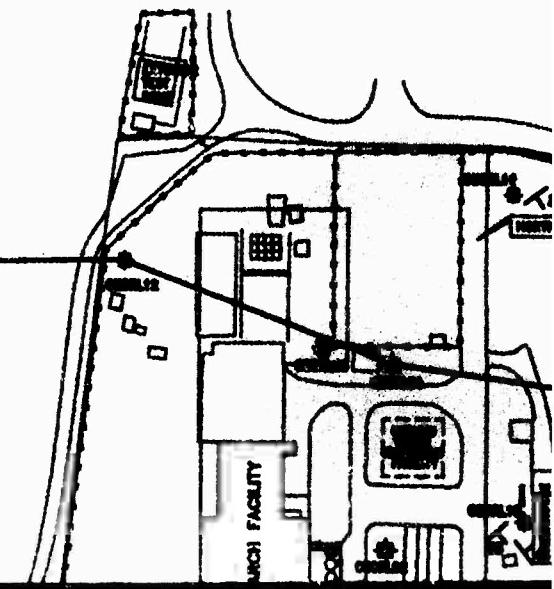
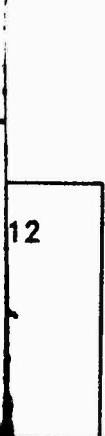
FIGURE 3-6
Cold Regions Research and Engineering
Laboratory
GELOGIC CROSS SECTION C-C'

PLAN VIEW:

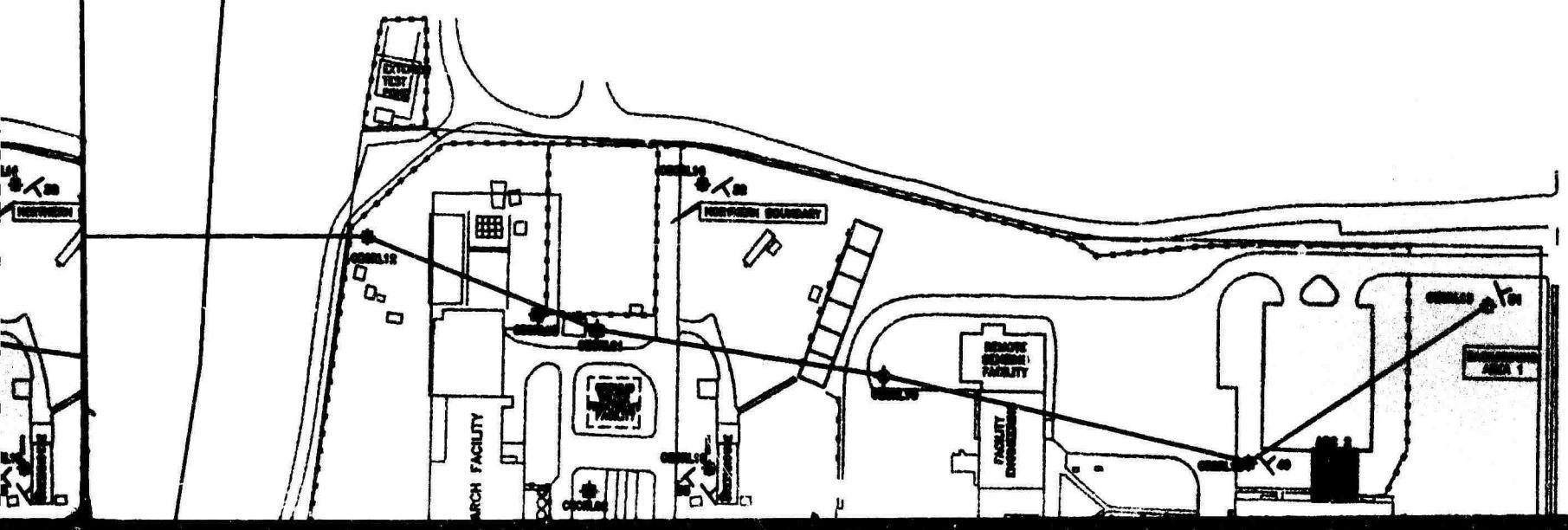


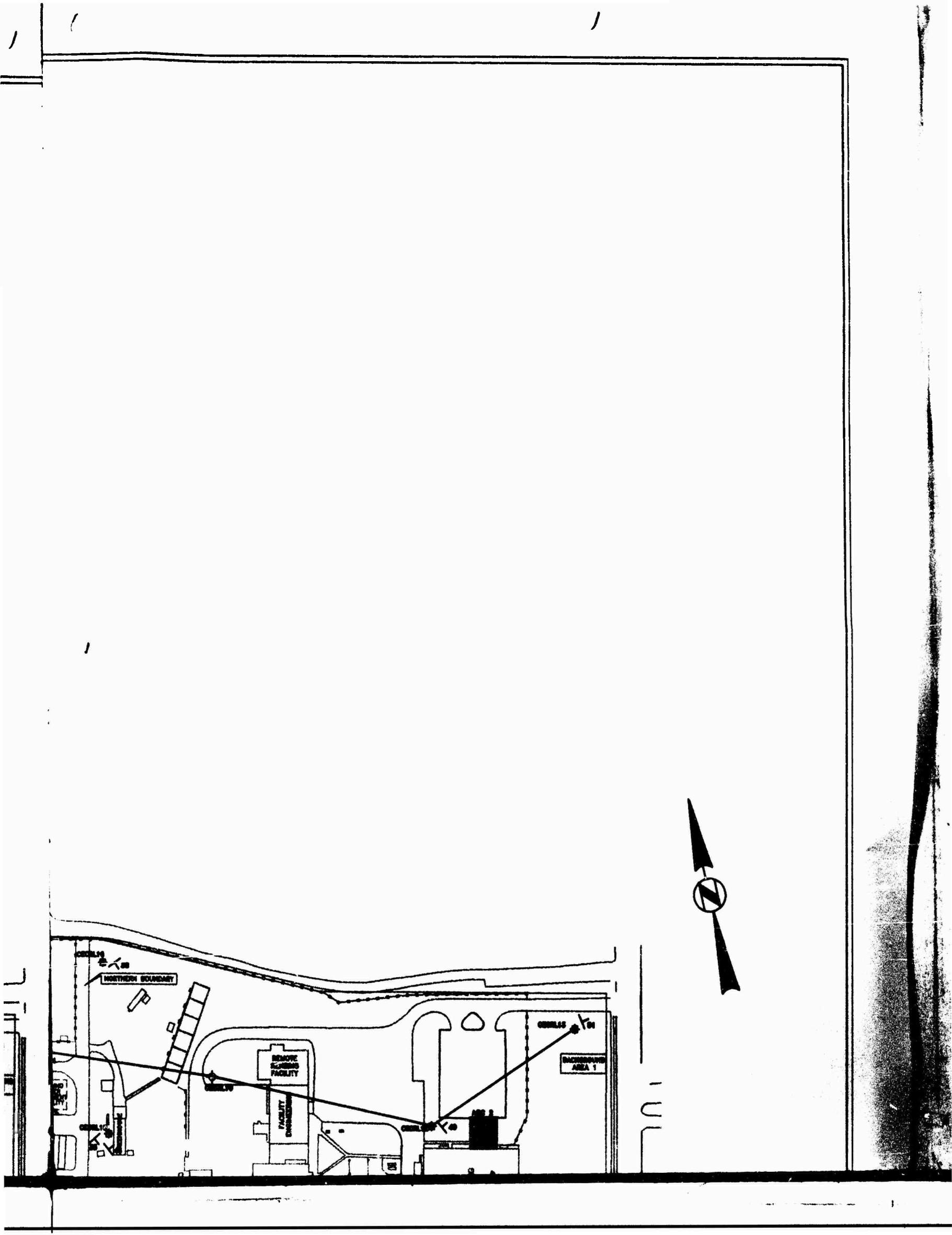
PEAKS

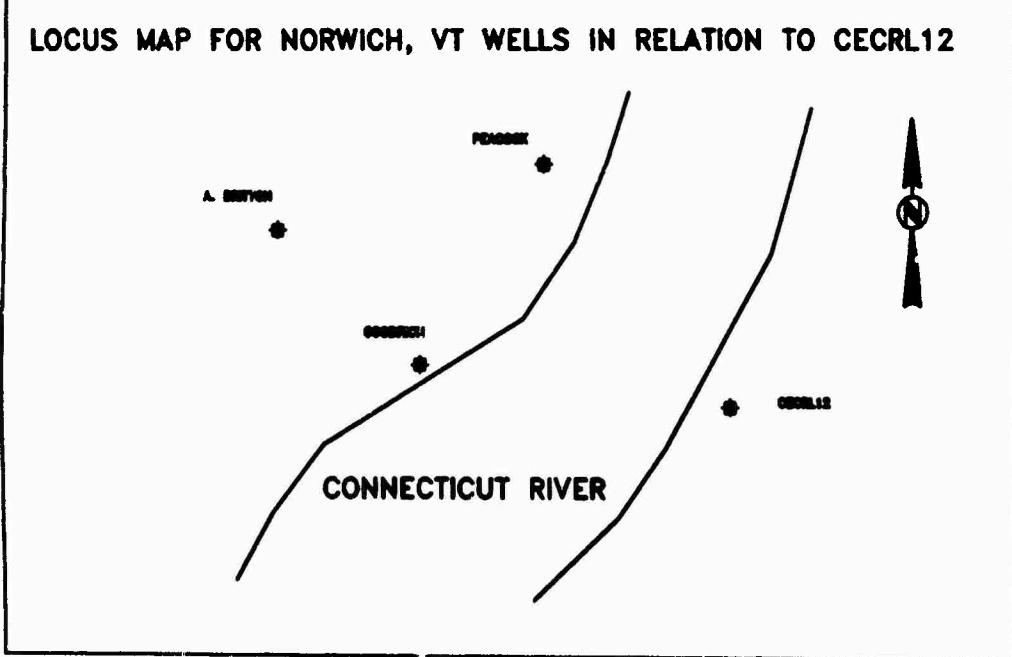
CONNECTICUT RIVER



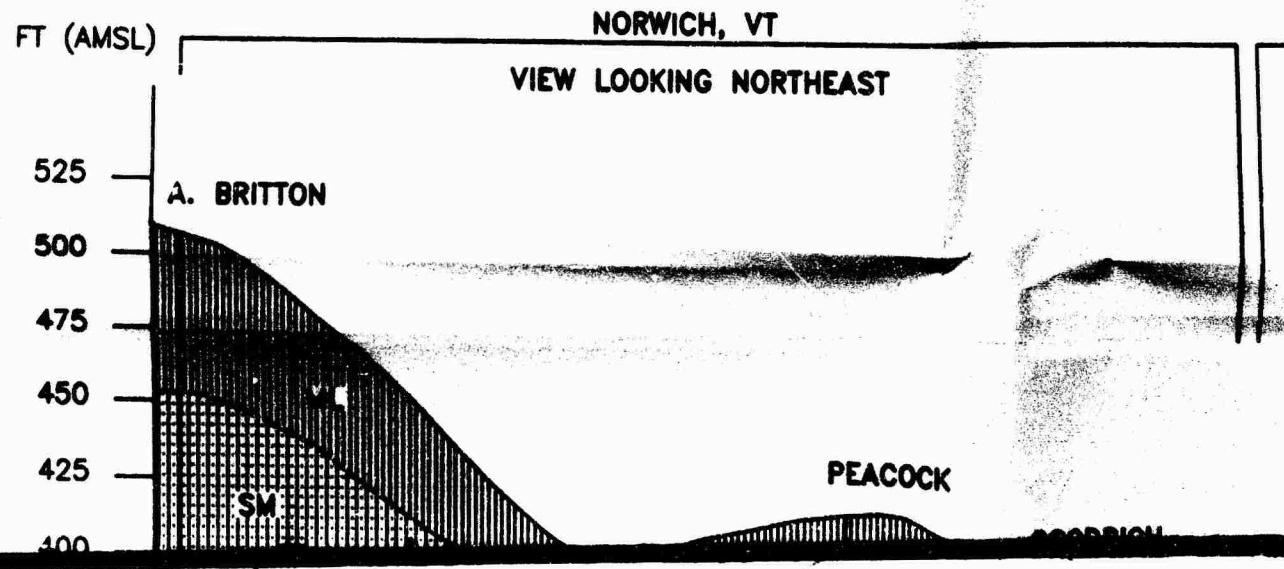
RIVER



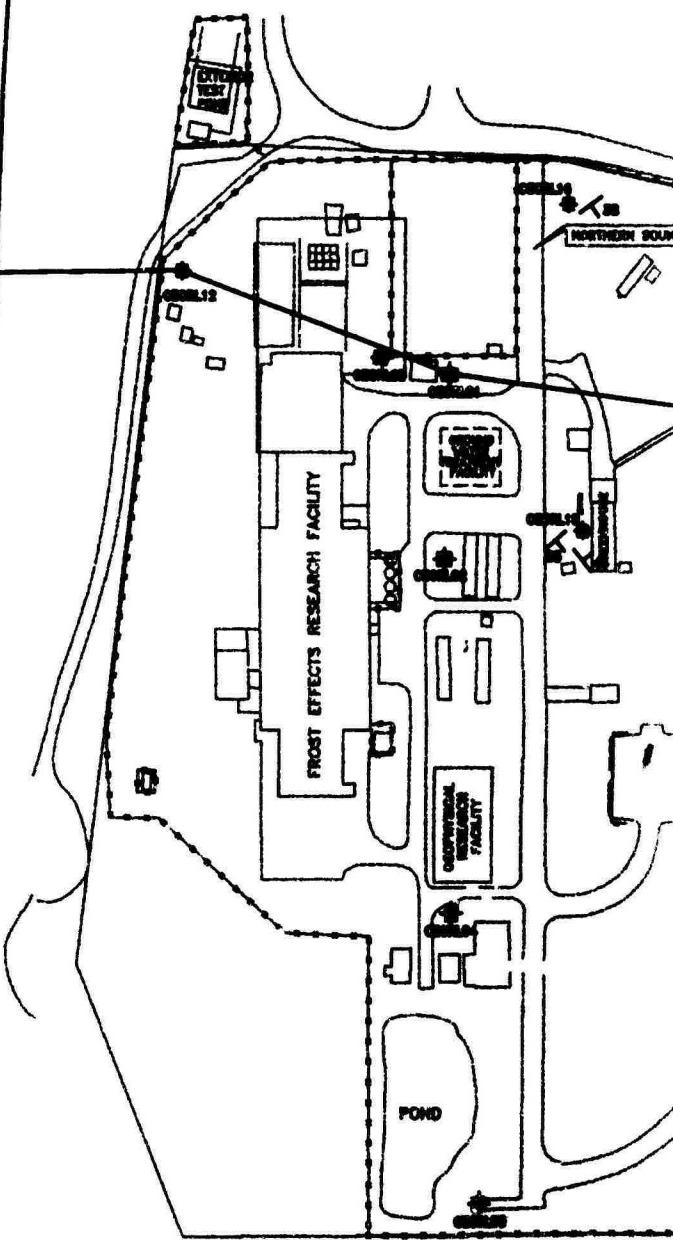




CROSS-SECTION:



CONNECTICUT RIVER



VT

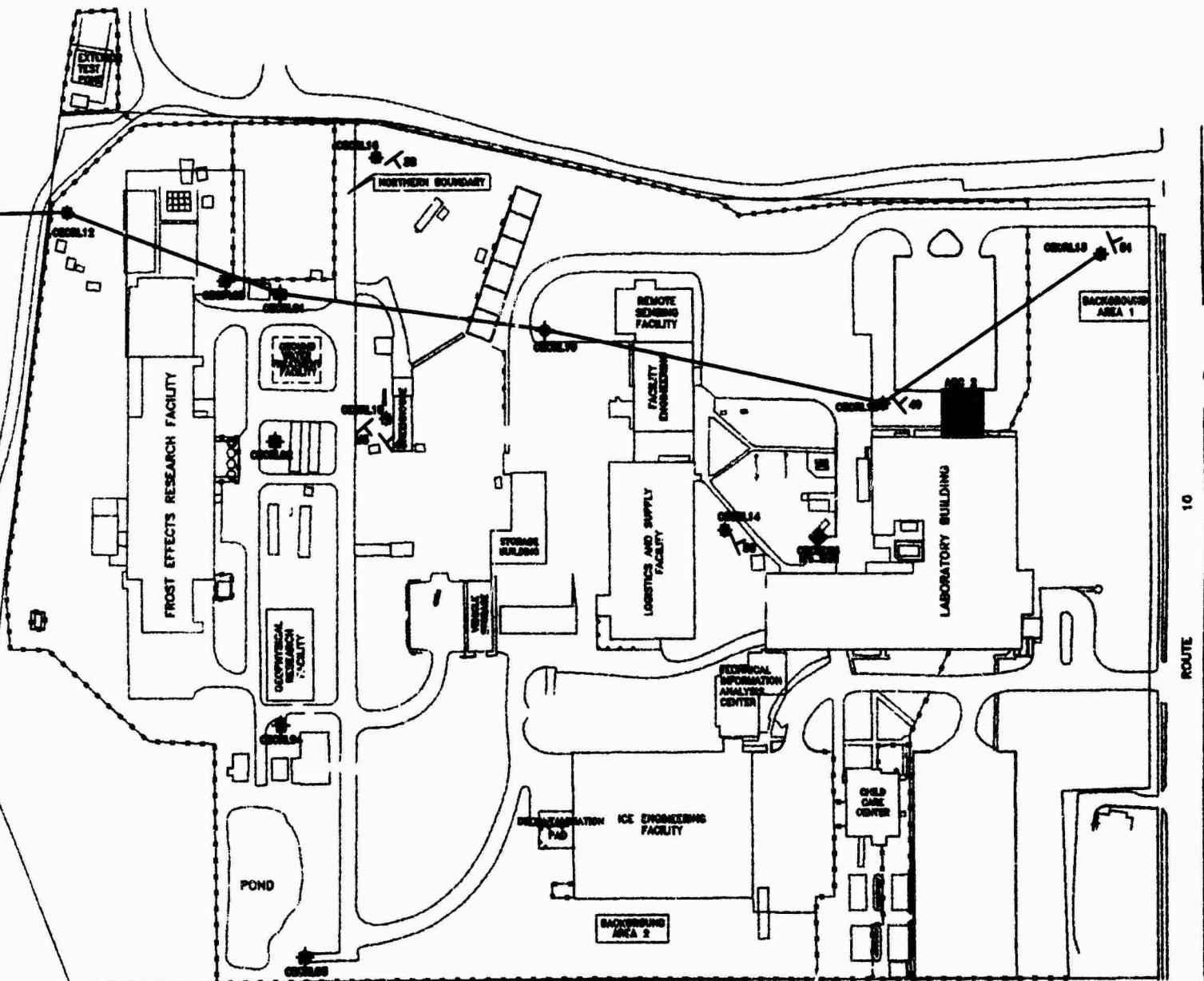
NORTHEAST

PEACOCK

GOODRICH

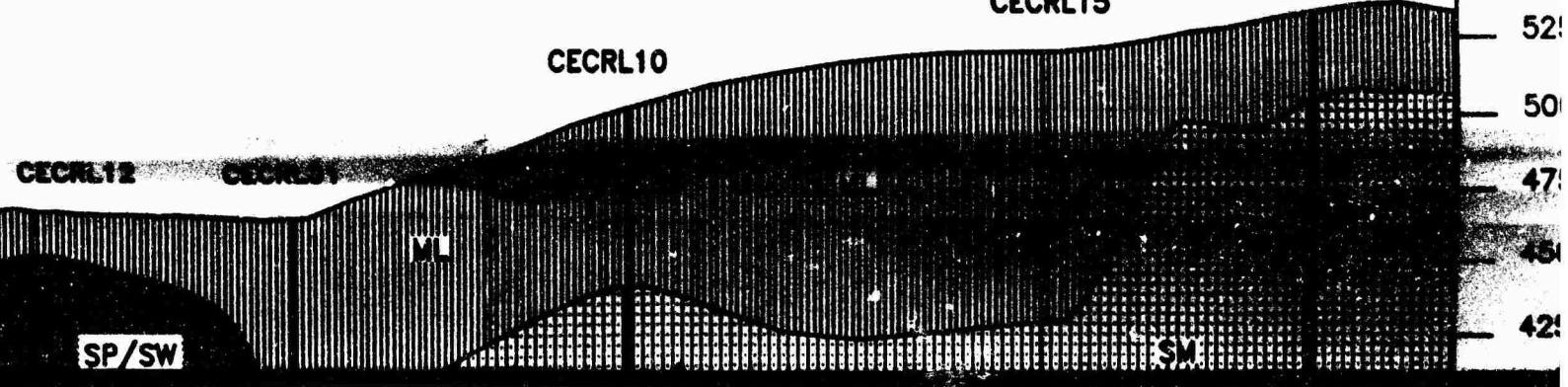
SP/SW

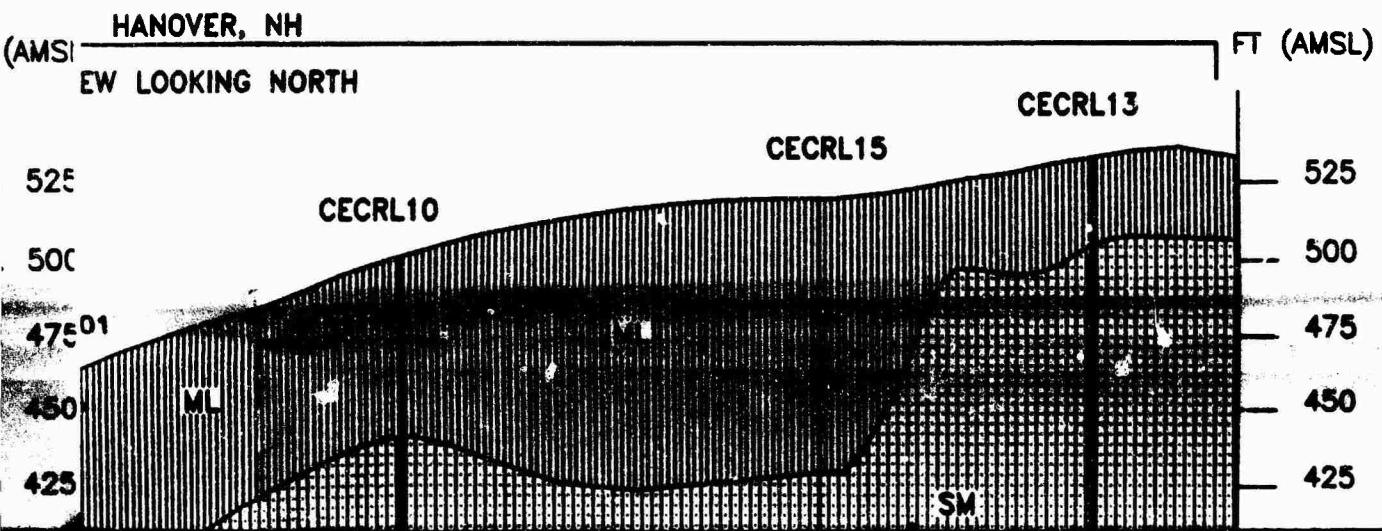
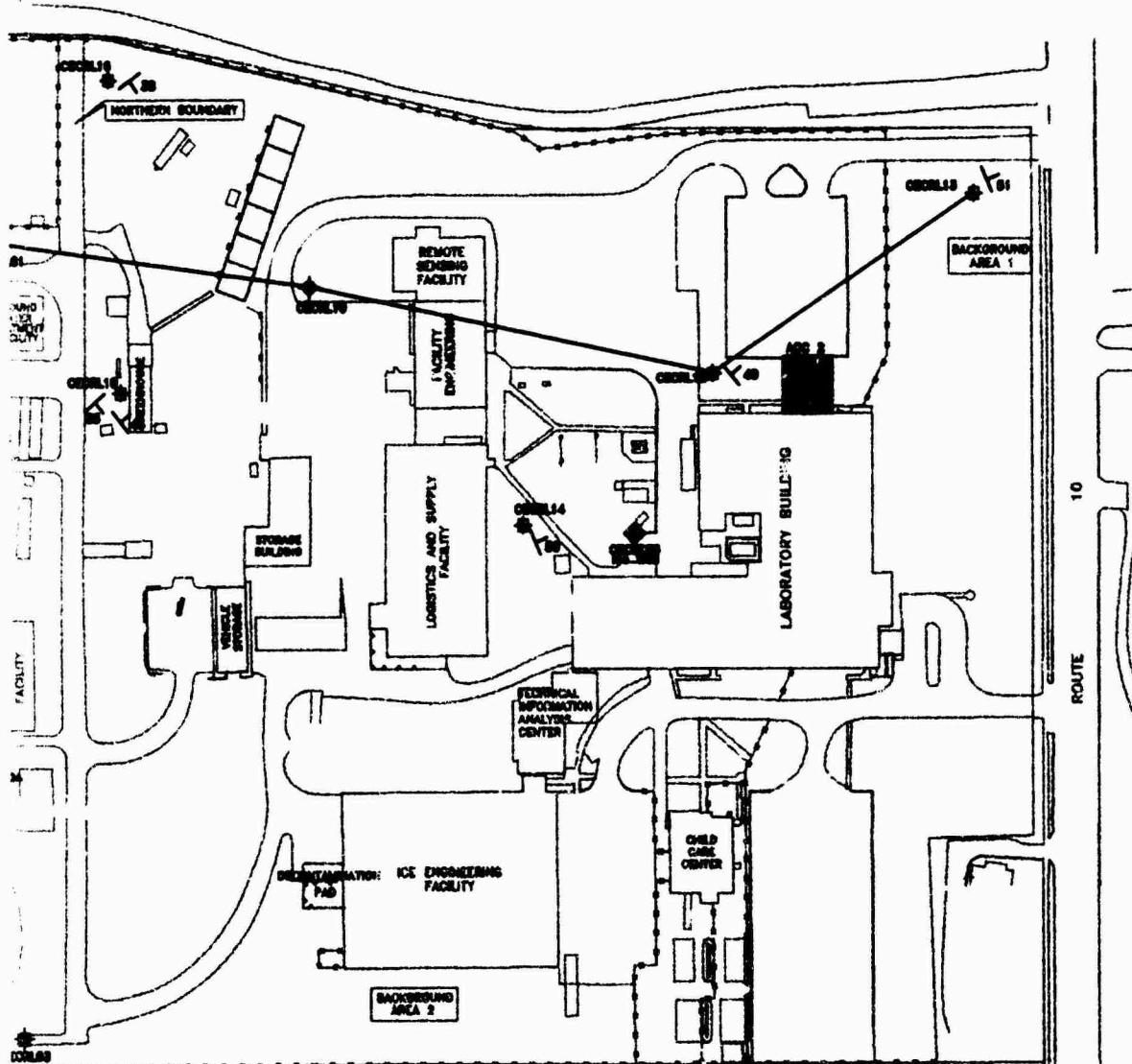
HANOVER,
VIEW LOOKING N



HANOVER, NH

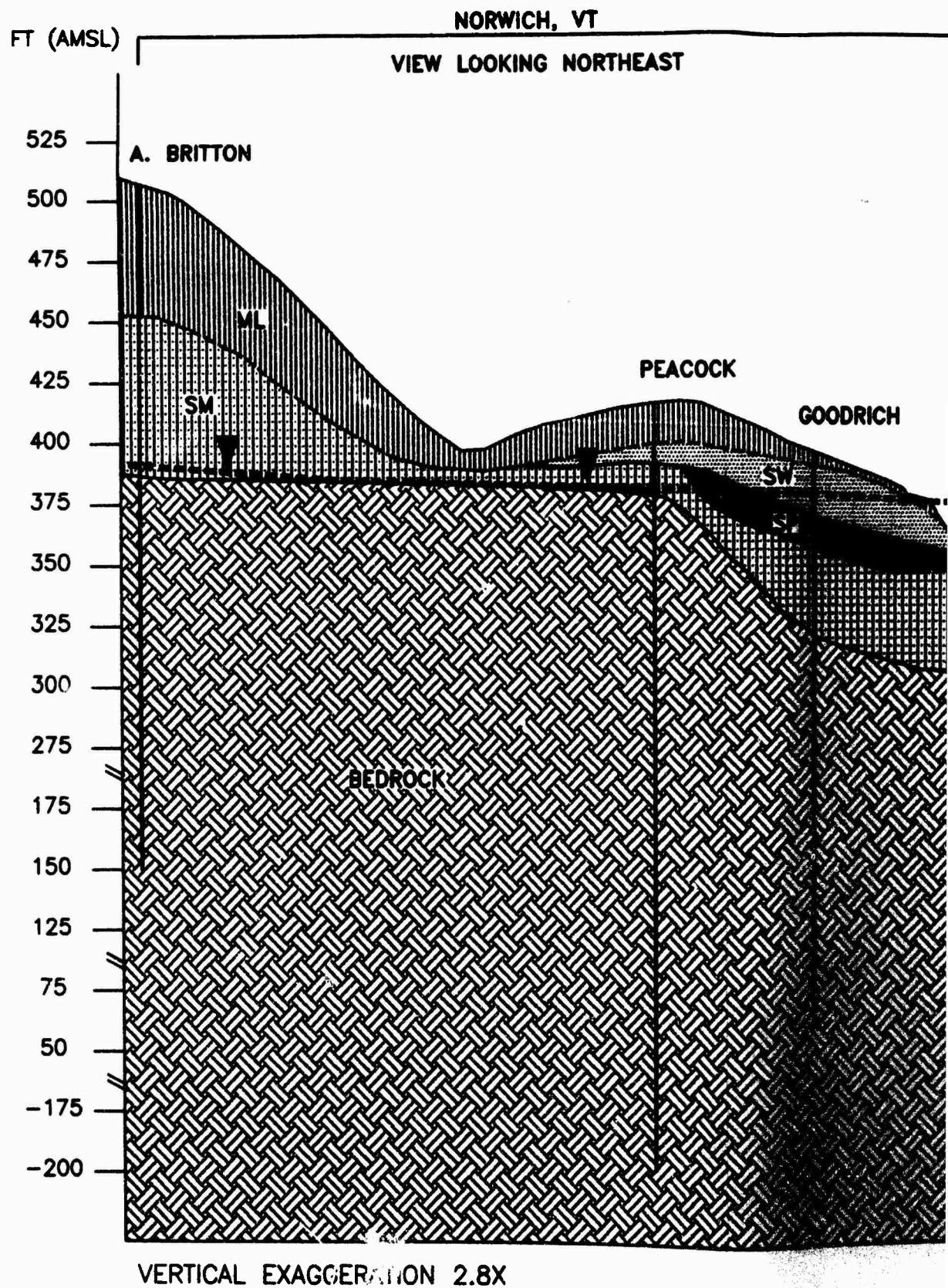
VIEW LOOKING NORTH





CONNECTICUT RIVER

CROSS-SECTION:



Geology on west side of Connecticut River.



ZWICH, VT

LOOKING NORTHEAST

H
VIEW

CECRL12 CECRL13

PEACOCK

GOODRICH

SW

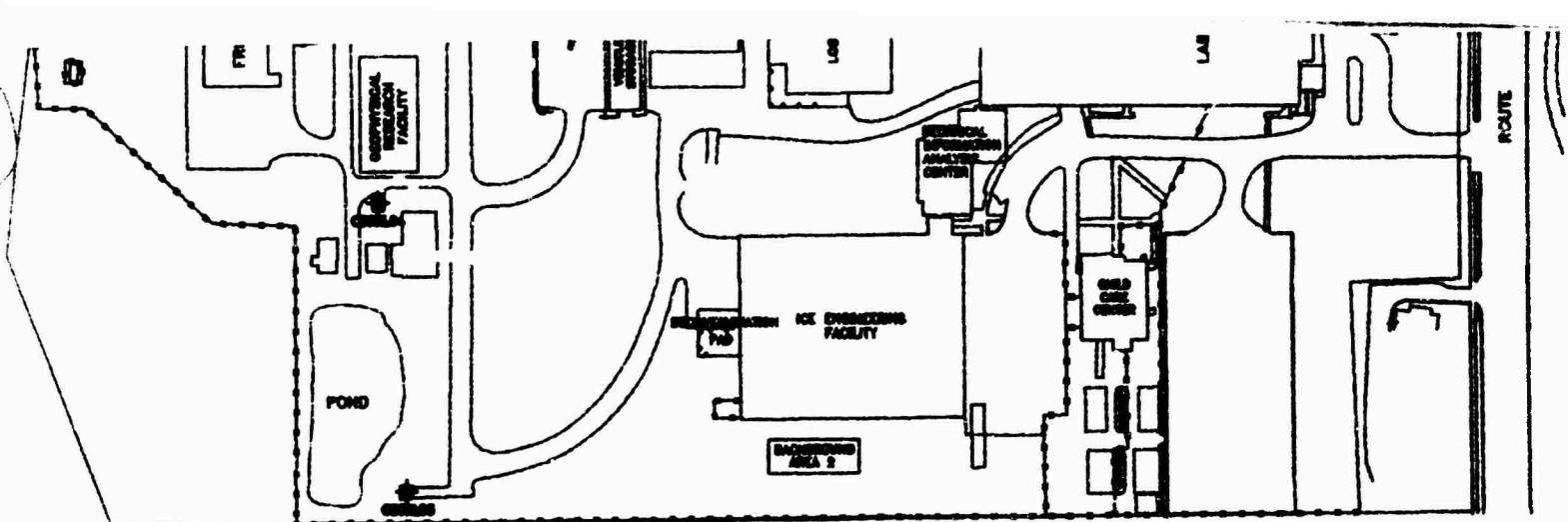
SP

CONNECTICUT RIVER

SM

ESKER

SP/SW



HANOV

EW LOOK

HANOVER, NH

VIEW LOOKING NORTH

FT (AMS)

CECRL13

CECRL15

CECRL10

CECRL12

CECRL01

ESKER

SP/SW

ML

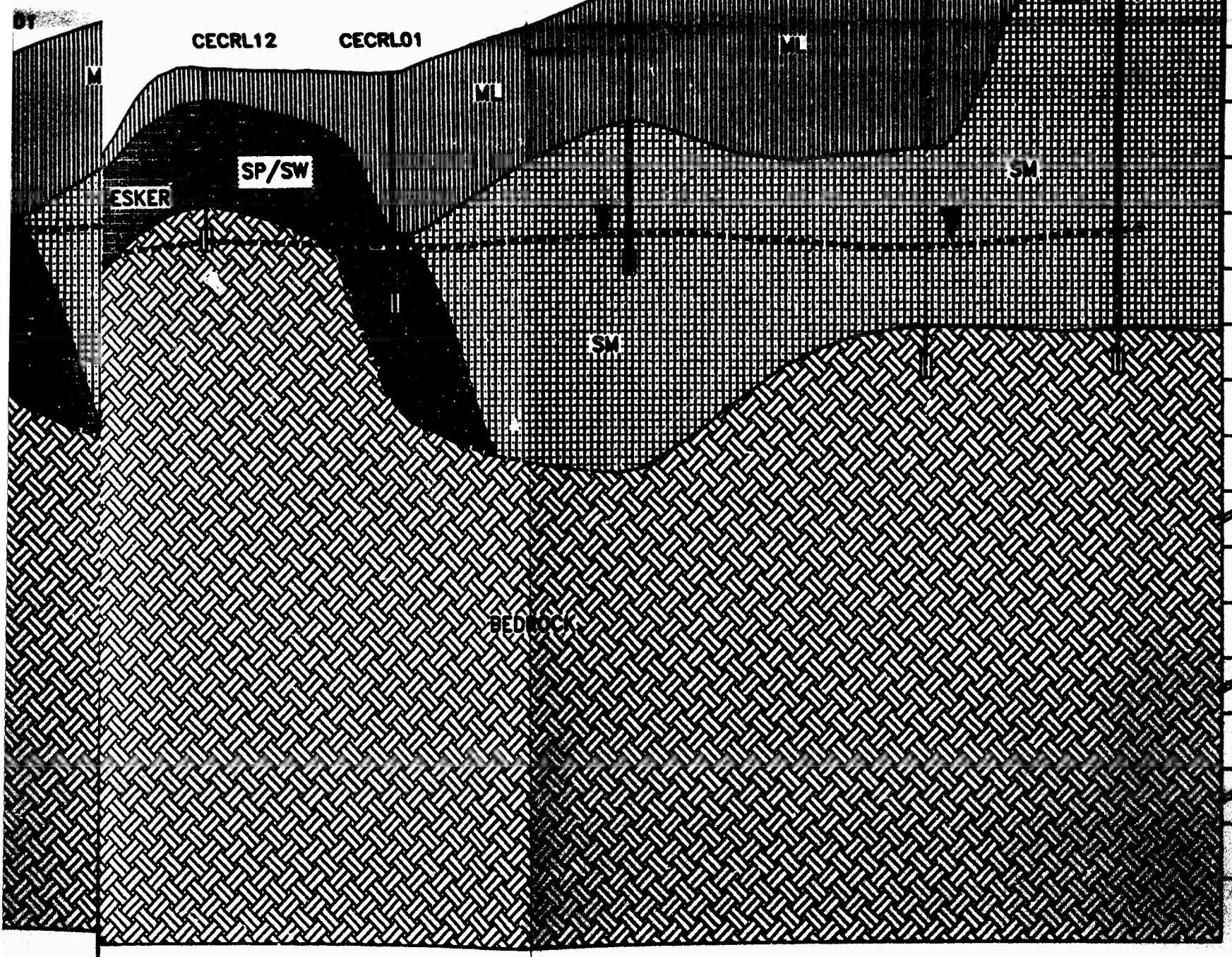
ML

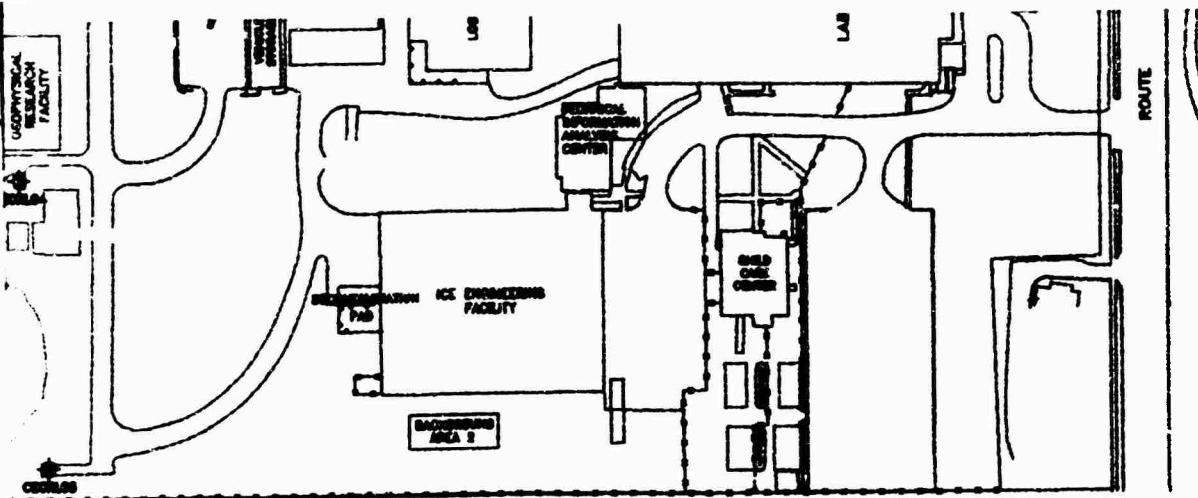
SM

SM

BEDROCK

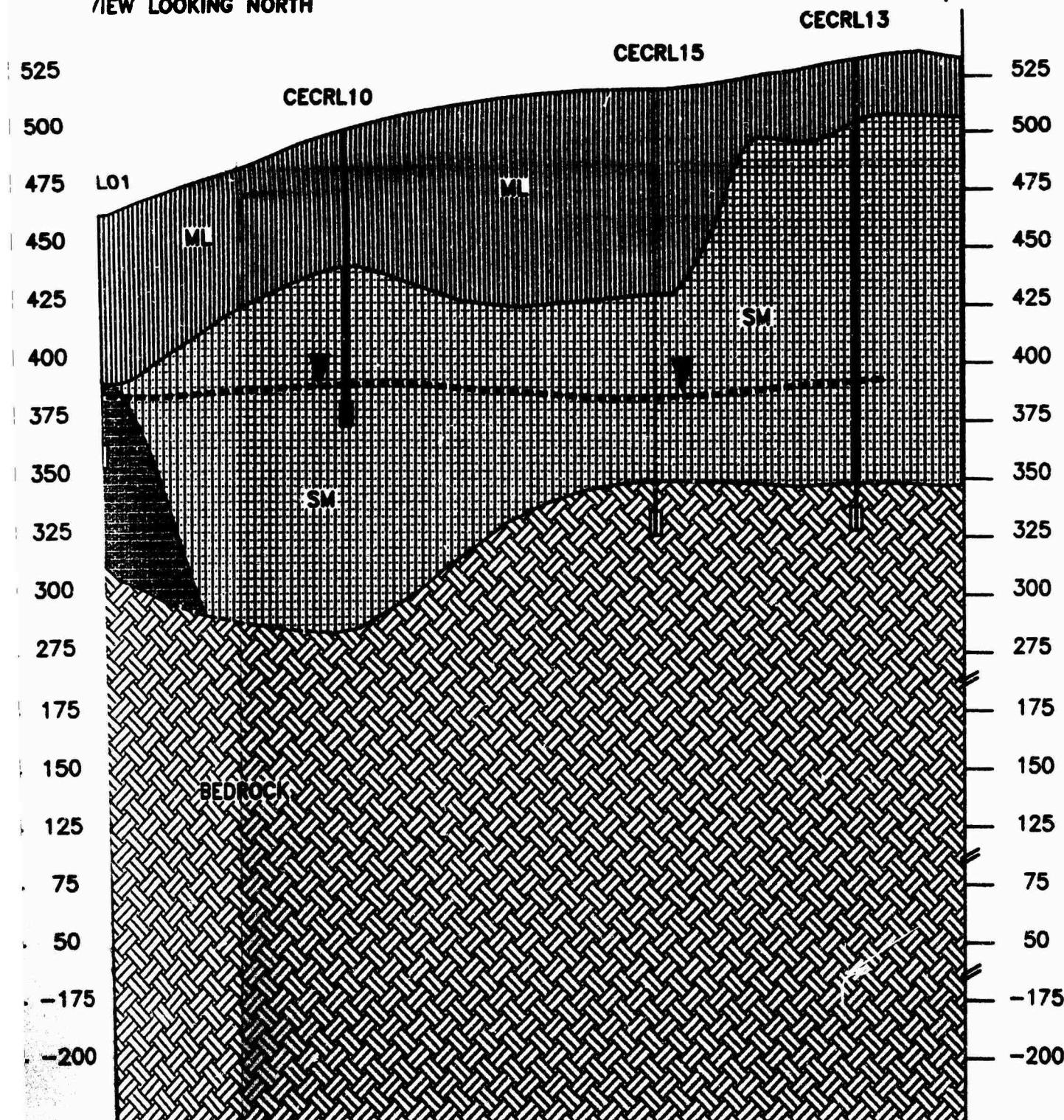
52
50
48
47
45
42
40
37
35
32
30
27
11
10
7
5
3
1

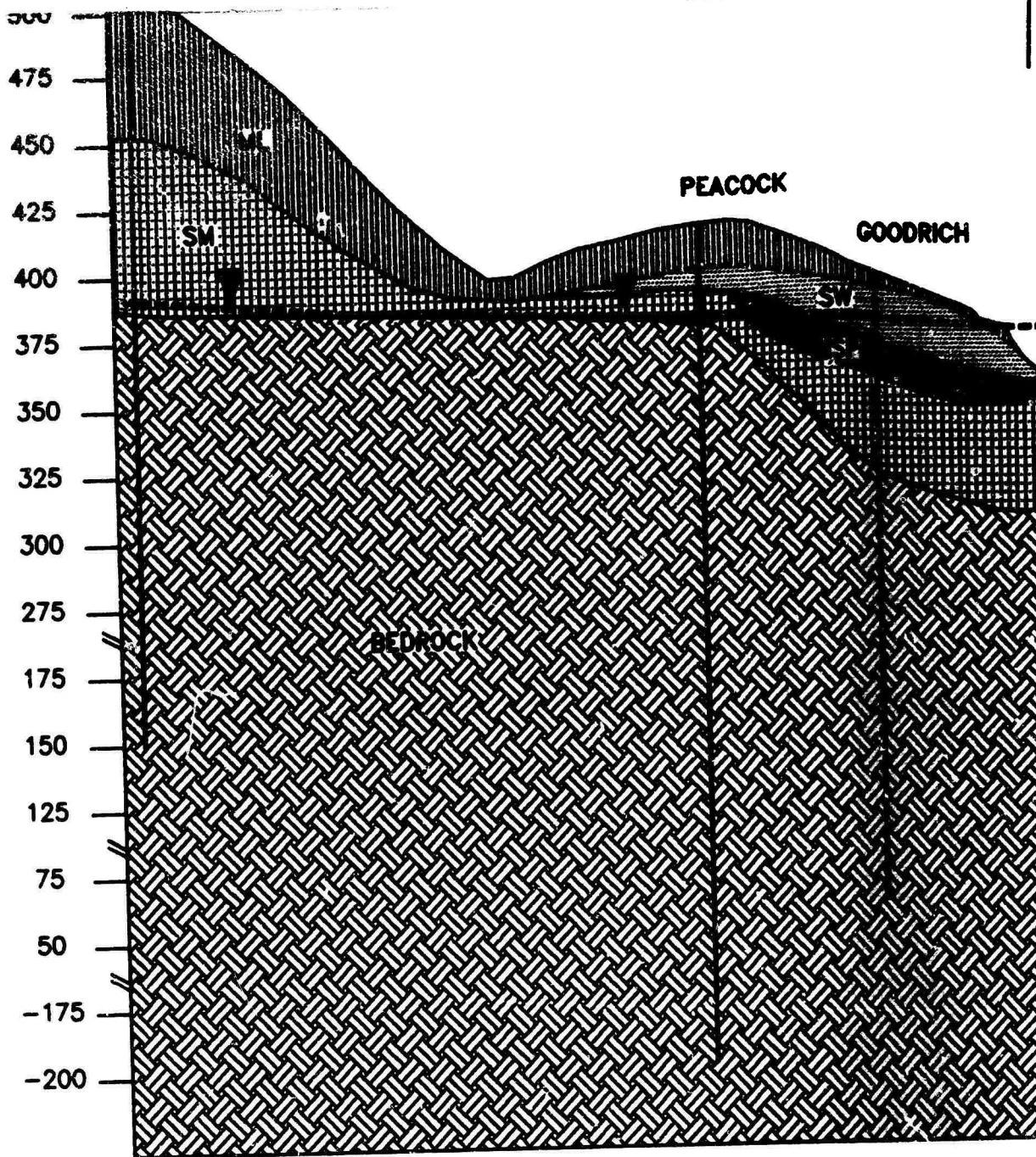




(AMSL) HANOVER, NH FT (AMSL)

VIEW LOOKING NORTH

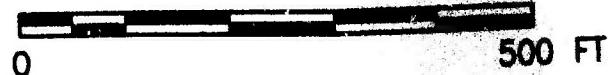




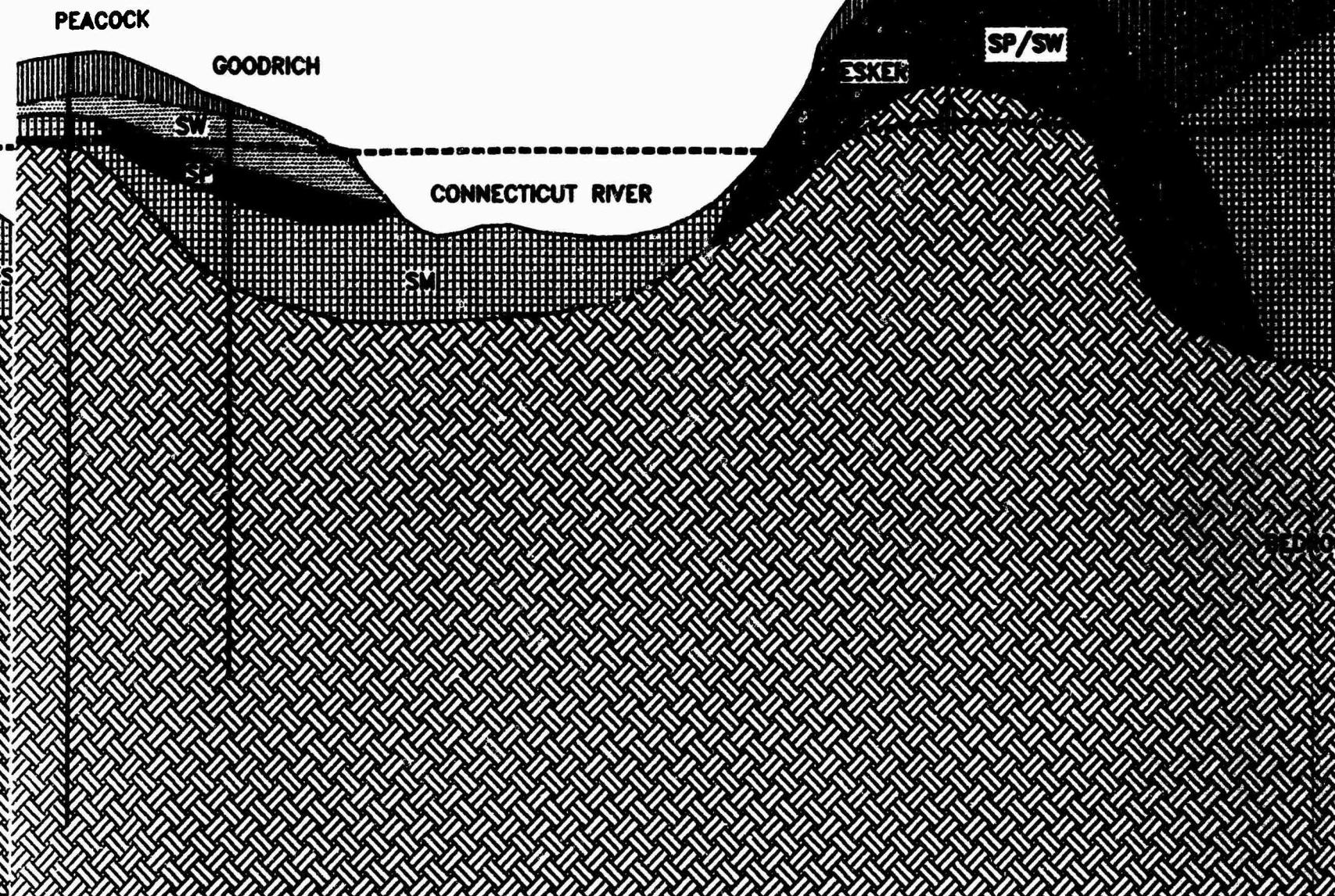
VERTICAL EXAGGERATION 2.8X

Geology on west side of Connecticut River is
interpreted from data provided in Johnson Company,
July 1993 report to VTDEC.

HORIZONTAL SCALE



PREPARED FOR:	USAEC	
DATE:	SCALE:	AS SHOWN
FEB. 1994		67063



t River is
Johnson Company,

HORIZONTAL SCALE



500 FT.



		DRAWN BY: (INITIALS)
063-	DWG. NO. 67063-065	APPROVED BY: (INITIALS)

Arthur D. Little

CECRL12

CECRL01

ML

475

450

425

400

375

350

325

300

275

175

150

125

75

50

-175

-200

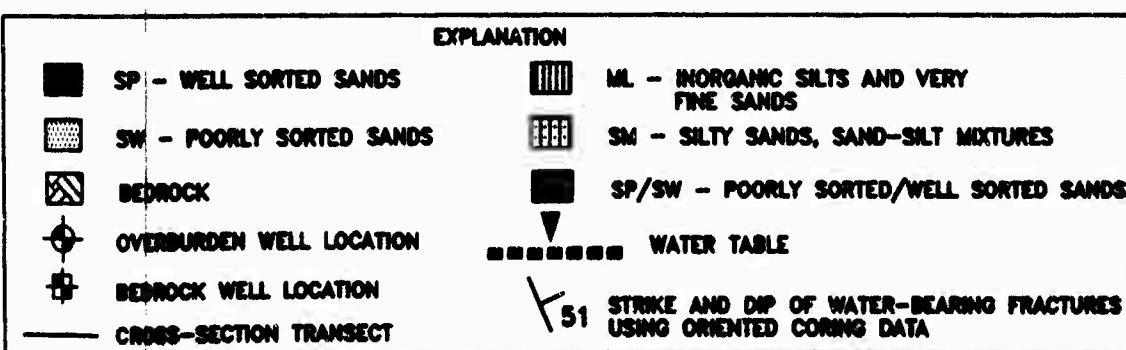
SP/SW

SM

SM

BEDROCK

SP - WELL
SW - POO
BEDROCK
OVERBURDEN
BEDROCK 1
CROSS-SEC



TITLE:

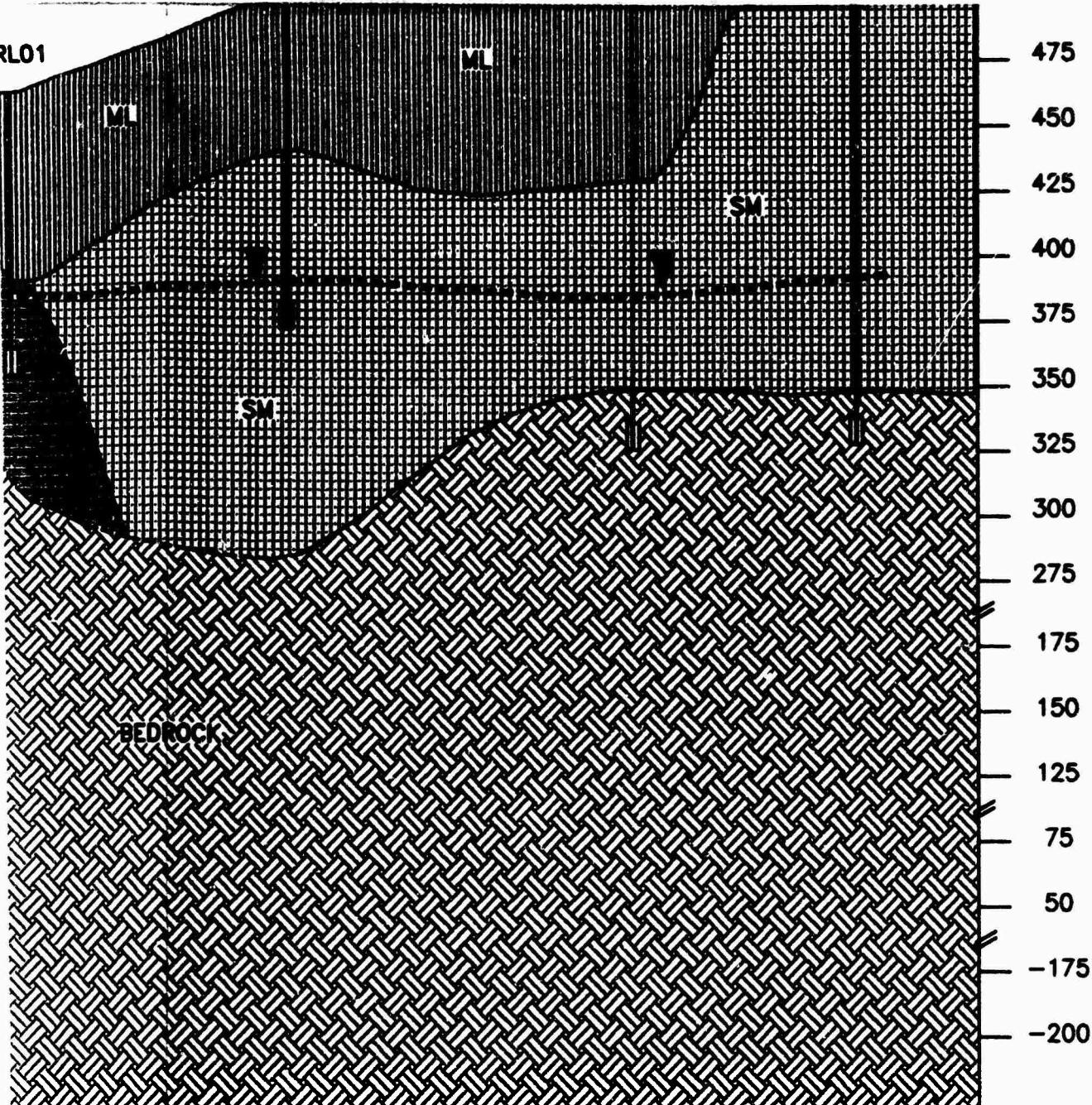
FIGURE 3-7

LOCATION OF SIGNIFICANT FEATURES

AND STUDY AREA

Cold Regions Research and Engineering
Laboratory**Arthur D Little**

RL01



EXPLANATION

SP - WELL SORTED SANDS

SW - POORLY SORTED SANDS

BEDROCK

OVERBURDEN WELL LOCATION

BEDROCK WELL LOCATION

CROSS-SECTION TRANSECT

ML - INORGANIC SILTS AND VERY FINE SANDS

SM - SILTY SANDS, SAND-SILT MIXTURES

SP/SW - POORLY SORTED/WELL SORTED SANDS

WATER TABLE

51 STRIKE AND DIP OF WATER-BEARING FRACTURES
USING ORIENTED CORING DATA

TITLE:

Little

FIGURE 3-7
LOCATION OF SIGNIFICANT FEATURES
AND STUDY AREA
Cold Regions Research and Engineering
Laboratory

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Date: March 18, 1994

3.4.1 Overburden Geology

Specific background information regarding the regional glacial history is derived from Stewart (1961) and Stewart and MacClintock (1969). Most of the glaciofluvial and glaciolacustrine sediments that comprise the overburden geology at CRREL and vicinity were deposited during advance and retreat of the Shelburne State of the Wisconsin period. The glacial advance, which occurred approximately 20,000 years ago, was associated with glaciofluvial deposition. This deposition was generally restricted to the axis of the Connecticut River Valley. The glacial retreat, which occurred approximately 13,000 to 11,000 years ago, was associated with glaciolacustrine deposition, in conjunction with the local deposition of ice-contact till during intermittent re-advances of the ice sheet. However, no till units have been documented at CRREL.

3.4.1.1 Glaciofluvial Units at CRREL. Glaciofluvial sediments at CRREL were deposited in a subglacial stream. Esker deposits, originating from streams or rivers located within or beneath a glacier, result in deposits with a unique sedimentary composition and geomorphic expression. Glacial fluvial systems are typically high-energy environments so that fine detrital material is washed from the stream channel, leaving a relatively coarse-grained and chemically immature (i.e., diverse mineralogy) sand component in the channel. For fluvial systems that are surrounded by ice, sharp geologic contacts typically exist between the channel deposits and other deposits. The map pattern geometry of eskers is typically sinuous, similar to typical non-glacial fluvial systems, but can cross topographic boundaries such as hills and valleys.

A major esker passes through the western border of CRREL. The esker underlies AOCs 10, 11, 12, 15, and 16. The esker is 50 miles long, extending from Bradford, Vermont, north of CRREL to White River Junction, Vermont, south of CRREL. The esker crosses the Connecticut River approximately 3,500 feet north of CRREL and continues south on the New Hampshire side of the river for several miles.

Based on topographic expression and geologic logs, the esker is approximately 400 feet wide at CRREL (Figures 3-4 and 3-5). Immediately southwest of the CRREL boundary, the esker is exposed and forms a ridge. Within the property boundaries of CRREL, the esker deposits are buried beneath younger glaciolacustrine silt and clay. Esker deposits are documented as far east as wells CECRL03, CECRL17, and CECRL19. The contact between the overlying and adjacent lacustrine sediment is extremely sharp, based on boring logs associated with these wells. The thickness of the esker deposits is approximately 60 feet and, where present, rests directly on bedrock.

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Revision No.: 1
Date: March 18, 1994

The esker deposits have USCS Classifications of SP and SW and consist of densely packed fine to coarse sand. The sand typically has a salt and pepper color, reflecting a chemically immature mixture of quartz, feldspar, and dark metamorphic and igneous rock fragment grains. Thin layers of gravel (>1 foot) have been documented in logs from CECRL17 and CECRL19 (Appendix G).

3.4.1.2 Glaciolacustrine Units at CRREL. Glaciolacustrine sediments at CRREL were deposited during the formation of a glacial lake (Lake Hitchcock) that formed as melt water from the glacial retreat was dammed by a moraine in the Connecticut Valley near Middletown, Connecticut. The stratigraphy of glaciolacustrine sediments is complex and highly dependent on the geomorphology of the lake and the availability of proximal sources of sediment. In general, the lacustrine stratigraphy consists of thin beds ranging in composition between clay and fine sand, interbedded with thicker beds of sand. The varied, thin beds represent seasonal deposition cycles, while thicker sand beds were deposited in a deltaic setting from sources near the lake.

Sediment of glaciolacustrine origin are present at all locations at CRREL. West of the lower terrace access road, the lacustrine deposits overlie the esker. At the remainder of the site, the lacustrine deposits comprise the entire overburden stratigraphy. The stratigraphy of the lacustrine sediment consists of three main units: a fine silty sand, a silt, and a silty clay. Figures 3-4 to 3-6 show the distribution of the major lacustrine units. Table 3-1 shows the results of geotechnical analyses (particle size distribution and Atterberg Limits) on selected samples from each of the lacustrine units.

The fine silty sand (SM) is the basal lacustrine unit for the eastern two-thirds of CRREL. The unit is predominately composed of brown, fine silty sand, but frequently contains laminations of silt or medium sand. Samples of the SM unit have compositional ranges of 66 to 87 percent sand, 13 to 29 percent fines (silt and clay), and 0 to 5 percent gravel (Table 3-1). Based on available data, this unit has a maximum thickness of at least 160 feet (CECRL07). Borings on the lower terrace of CRREL (CECRL12, CECRL17, CECRL19, and 15SB2) indicate a dramatic decrease in the thickness and stratigraphic persistence of this unit. At the position of the lower terrace access road, this unit is approximately 15 to 20 feet thick, and directly overlies the esker deposits (Figure 3-4). West of this road, the SM unit is interbedded with other lacustrine deposits. The geometry, composition, and bedding features present in these units suggest a deltaic origin from a source east of CRREL.

The silt (ML) overlies the SM unit and esker deposits at CRREL. This unit is composed of olive gray to yellowish brown silt typically interbedded with layers of fine sandy silt. The layering between these two silt units varies from less than 1 inch to several feet. Samples of the ML unit have compositional ranges of 0 to 79 percent

Table 3-1 Geotechnical Analysis of Soil Samples

Sample ID	Depth (ft)	Depth (m)	Grain Size (mm)	Dry Density (lb/ft³)	Wet Density (lb/ft³)	Water Content (%)	Solid Content (%)	Plastic Limit (%)	Shrinkage Limit (%)	Atterberg Liquid Limit (%)	Atterberg Plastic Limit (%)	Atterberg Shrinkage Limit (%)	Unconfined Compressive Strength (psi)	Unconfined Compressive Strength (kPa)	Consistency Class
CECRL07	S-3	13-15	0	1	99	29	27	-	-	-	-	-	2	CL	
CECRL07	S-6	28-30	0	4	96	29	26	13	-	-	-	-	3	CL	
CECRL07	S-14	150-152	0	87	-	-	-	-	-	-	-	-	-	SM	
CECRL07	S-17	174.5-176.5	0	72	28	-	-	-	-	-	-	-	-	SM	
CECRL08	S-2	38-40	5	68	29	-	-	-	-	-	-	-	-	SM	
CECRL08	S-4	79-81	0	72	28	-	-	-	-	-	-	-	-	SM	
CECRL08	S-7	139-141	1	79	20	-	-	-	-	-	-	-	-	SM	
CECRL09	S-2	38.5-40.5	1	0	99	30	26	-	-	-	-	-	4	ML	
CECRL09	S-4	78.5-80.5	1	39	60	23	21	-	-	-	-	-	2	ML	
CECRL09	S-8	139-141	0	89	11	-	-	-	-	-	-	-	-	SM	
CECRL10	S-3	58-60	-	28	69	NP	NP	-	-	-	-	-	-	ML	
CECRL10	S-5	98-100	0	56	44	NP	NP	-	-	-	-	-	-	ML	
CECRL10	S-7	124-128	0	84	16	-	-	-	-	-	-	-	-	SM	
CECRL11	S-1	18-20	0	10	90	29	26	-	-	-	-	-	3	ML	
CECRL11	S-2	38-40	2	0	96	40	28	-	-	-	-	-	12	ML	
CECRL11	S-3	58-60	0	4	96	29	25	-	-	-	-	-	4	ML	
CECRL11	S-7	118.5-120.5	0	79	21	-	-	-	-	-	-	-	-	ML	
CECRL12	S-5	22.5-24.5	13	80	7	-	-	-	-	-	-	-	-	SW-SM	
CECRL12	S-8	37.5-39.5	48	48	4	-	-	-	-	-	-	-	-	SW	
CECRL12	S-12	57.5-59.5	0	94	6	-	-	-	-	-	-	-	-	SP	
CECRL17	NIBX001	27-29	0.0	2.5	97.5	NP	NP	-	-	-	-	-	-	ML	
CECRL17	NIBX002	62-64	0.0	0.0	100.0	NP	NP	-	-	-	-	-	-	ML	
CECRL19	51BX005	67-69	0.0	3.7	96.3	NP	NP	-	-	-	-	-	-	ML	
CECRL19	51BX006	92-94	0.0	9.7	90.3	NP	NP	-	-	-	-	-	-	ML	
2SB5	21BX007	22-24	1.0	24.2	74.8	NP	NP	-	-	-	-	-	-	ML	
2SB6	21BX005	17-19	0.0	5.3	94.7	NP	NP	-	-	-	-	-	-	ML	
9SB2	91BX005G	30-41	2.1	3.7	94.2	NP	NP	-	-	-	-	-	-	ML	
13SB3	31BX013G	35-37	0.0	0.0	100.0	NP	NP	-	-	-	-	-	-	ML	
13SB4	31BX019C	35-37	0.0	0.0	100.0	NP	NP	-	-	-	-	-	-	ML	
15SB2	51BX005	14-16	0.0	82.6	17.4	NP	NP	-	-	-	-	-	-	SM	

Notes:

* Data for CECRL07-12 modified from Ecology and Environment, Table 6-1, Phase I RI (1992)

** Percentages

*** Based on the Unified Soil Classification System (USCS)

CL silty clay

ML clayey silt/silty or clayey fine sands

SM silty sand

SW well-graded sands/gravelly sands with trace of silt

SP poorly-graded sands/gravelly sands

NP non-plastic

SW-SM gravelly sand with trace of silt

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sand, 21 to 100 percent fines, and 0 to 3 percent gravel (Table 3-1). Boring logs indicate that the thickness of the ML unit varies between 20 feet (CECRL07) and 110 feet (CECRL17). In general the thickness of the ML unit increases from east to west across CRREL, reaching a maximum thickness in the vicinity of the lower terrace access road, where it directly overlies esker deposits (Figures 3-3 and 3-4).

Various silty clay to clay units (CL) occur within both the SM and ML deposits. Within the SM unit, layers of CL are thin (approximately 1 or 2 feet) and have only been documented at CECRL10. Within the ML unit, the CL lithologies occur frequently and range in thickness between 10 and 40 feet. The CL lithologies are a major component of the ML stratigraphy in the vicinity of AOC 15, and in parts of AOC 9 and AOC 13.

3.4.2 Bedrock Geology

The bedrock beneath CRREL consists of metasedimentary rock of the Cambro-Ordovician-age Post Pond volcanic member of the Oxfordville Formation (Lyons, 1955). These rocks were formed from volcanic detritus that was subsequently metamorphosed during the Taconic Orogeny, and today occur as multiply deformed hornblende schist, amphibolite, and feldspathic schist. Bedrock coring at five locations (CECRL13, CECRL14, CECRL15, CECRL16, and CECRL18) indicates that bedrock beneath CRREL consists of amphibolite and paragneiss.

The primary mineralogy of the amphibolite is hornblende (amphibole) with minor amounts (typically >10 percent) of plagioclase and biotite. These minerals are segregated into bands that define the dominant foliation. Partial alteration of hornblende to chlorite gives the rock a greenish-black to grayish-black appearance. Amphibolite is the dominant type of bedrock at each coring location, except CECRL16.

The primary mineralogy of the paragneiss is plagioclase, quartz, hornblende, and biotite. The dark minerals (hornblende and biotite) and light minerals (plagioclase and quartz) are segregated, resulting in a strongly defined foliation. Gradational contacts between zones of paragneiss in amphibolite occur at CECRL14, CECRL15, and CECRL18. At CECRL16, paragneiss was the only bedrock cored, but it was not present at CECRL13.

3.4.2.1 Structural Features. CRREL is located immediately east of a major normal fault, known as the Ammonoosic Fault. In the vicinity of CRREL, the Ammonoosic Fault parallels the west bank of the Connecticut River and is oriented approximately N20E, dipping 30° to 50° to the west (Gatto and Shoop, 1991). Based on reported characteristics of the Ammonoosic Fault, it is quite possible that splays off of the fault intersect the bedrock beneath CRREL.

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Structural fabrics in the rocks include the dominant foliation and one set of conjugate fractures oriented at a high angle to the dominant foliation. In the vicinity of CRREL the orientation of the dominant foliation ranges between N20E and N40E and dips 20° to 50° to the west (Figure 3-7, Plan View). It is defined by the realignment, zonation, and recrystallization of mineral groups. Although this is the most pervasive structural feature in the bedrock at CRREL, open fractures parallel to the foliation are absent. Fractures parallel to the dominant foliation are annealed by recrystallized quartz, calcite, and pyrite. Most of the conjugate fractures are also annealed with similar secondary mineralization.

The location, orientation, and special features of open water-bearing fractures are described in Table 3-2. In general, these fractures are rare, occurring only 2 or 3 times over a 10-foot interval. Most of the open fractures occur as isolated single fractures, typically less than 0.5 cm thick. The one exception is a 0.3-foot thick open fracture zone at CECRL16. Iron staining is the most common weathering feature present on the surfaces of all open fractures.

Figure 3-8 is a graphical representation of the 14 water-bearing fractures documented in the cores, plotted on an equal area net. The poles to the planes of all of the fractures were contoured to illustrate the density distribution (in percent per 1 percent area) of the data. Two fracture orientations were determined from the contoured data -- the most common orientation of the water-bearing fractures, and the orientation of the largest water-bearing fracture from CECRL16. The vast majority of the fractures define a plane that strikes N53W and dips 46 E. However, the major fracture zone at CECRL16 strikes N35E and dips 38 E, and may represent a conjugate fracture to those oriented parallel to the dominant foliation.

A fracture trace analysis, field outcrop study, and borehole geophysical study was performed by The Johnson Company on the west side of the Connecticut River. Based on the fracture trace analysis and field outcrop study, the strongest fracture set has an orientation striking east-southeast. The second fracture set strikes south-southeast (Figure 3-7). The borehole geophysical investigation identified water-bearing fractures in the Peacock, Goodrich, and Britton wells, however, the orientation of the fractures were not determined in this study.

3.4.2.2 Bedrock Surface. Figure 3-9 is structural contour map of the bedrock surface beneath CRREL. Based on available borehole and geophysical data, the majority of CRREL is located on top of a buried asymmetric bedrock valley. The relatively shallow sloping eastern edge (0.09 feet/foot) of the valley is bordered to the east by AOC 2. East of AOC 2, the bedrock topography is flat, located at an elevation of approximately 340 feet above msl. The valley itself rests at an elevation between 290 and 270 feet above msl. The axis of the valley is oriented north-south beneath CECRL16/17 at the northern boundary, AOC 15 in the center of CRREL,

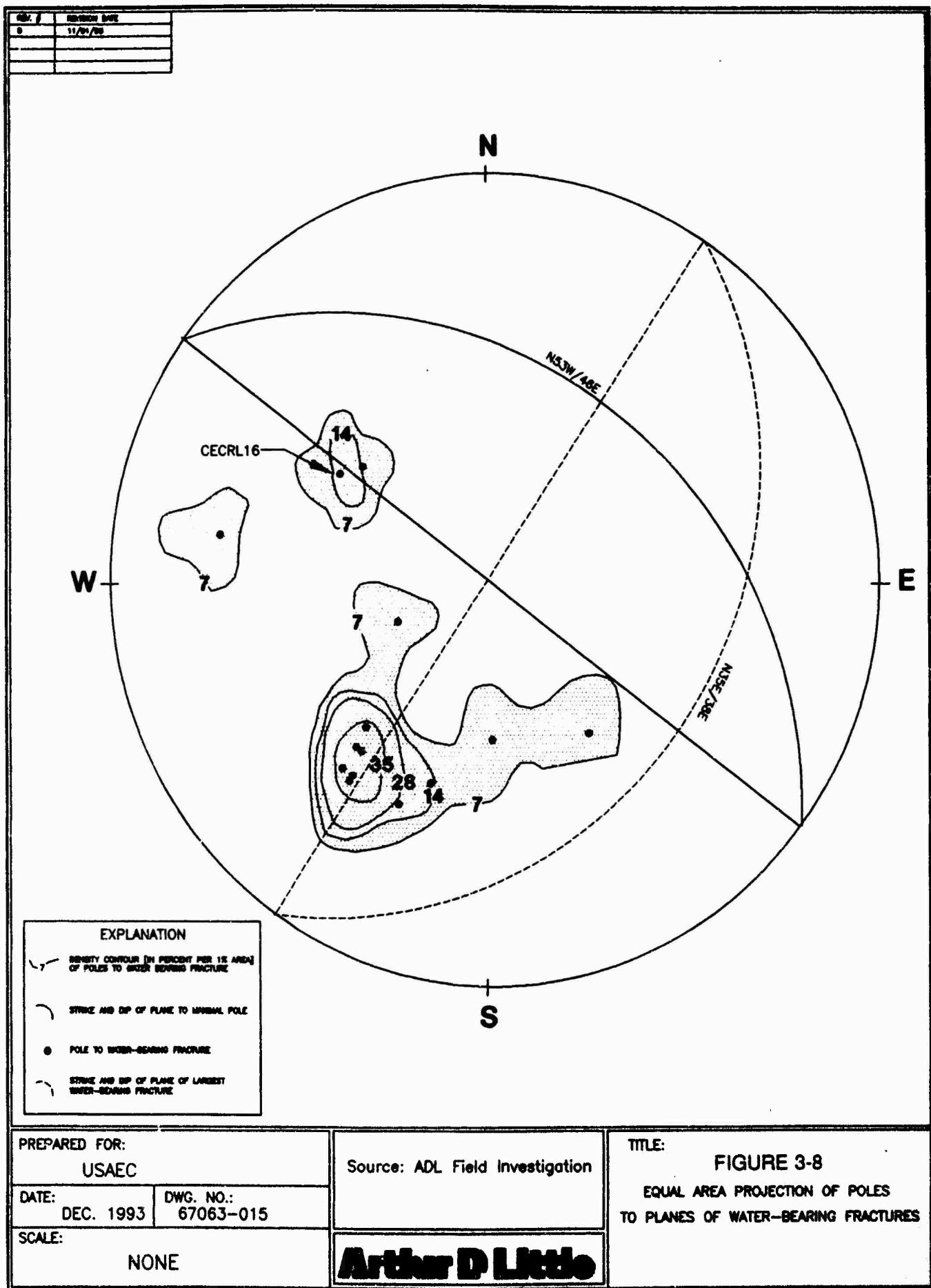
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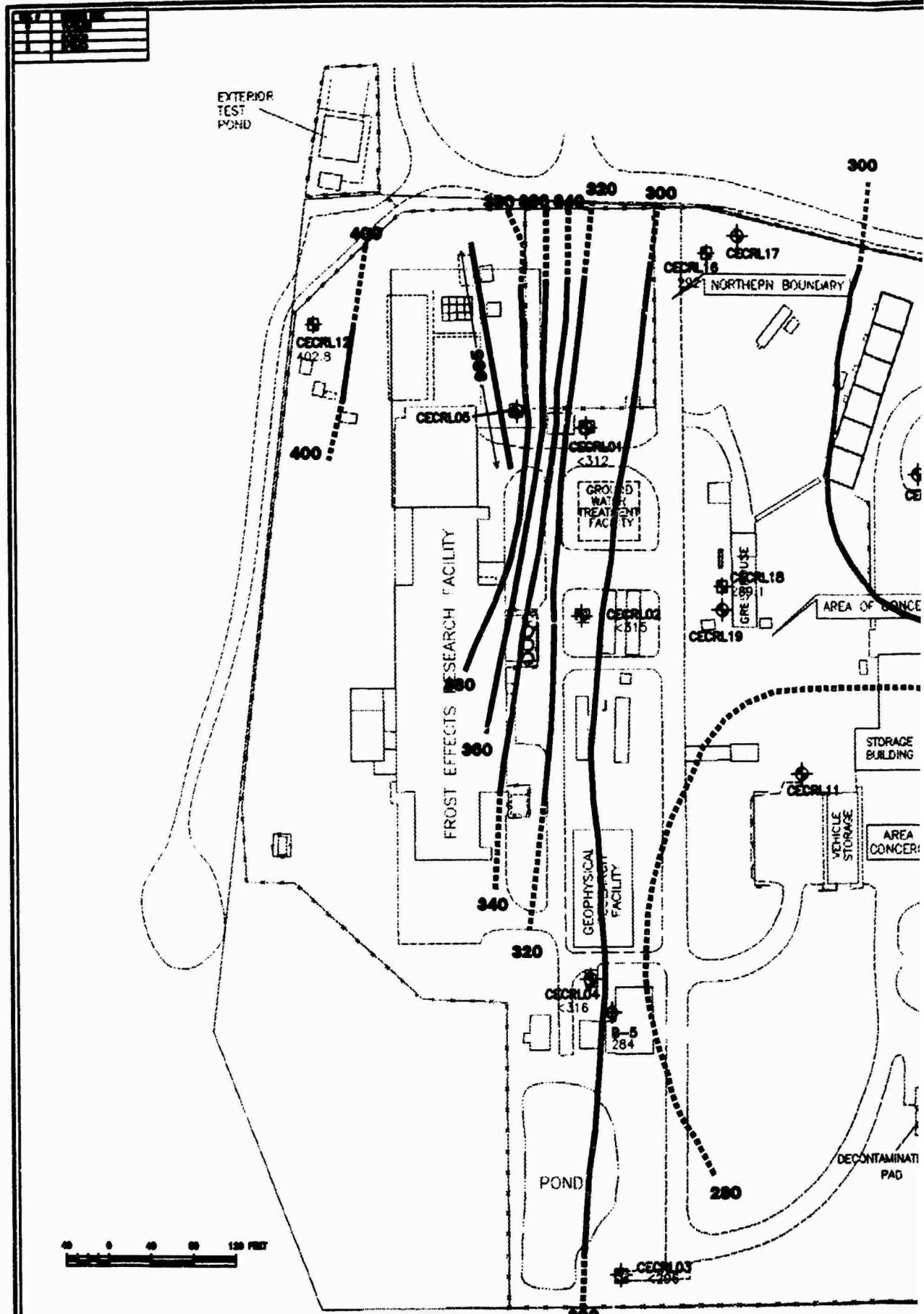
Table 3-2: Occurrence, Orientation, and Description of Water-Bearing Fractures

Well No. [Screen Interval]	Core Run	Core Interval	Orientation Data or Depth	Remarks
CECRL13 [203.0-193.0]	1	182.5-186.0	No Orientation Data	
	2	186.0-191.0	No Orientation Data	
	3	191.0-196.0	191.7 at N22W/21N 193.6 at N54W/51N 194.7 at N50W/50N	Moderate Iron Staining Heavy Iron Staining Heavy Iron Staining
	4	196.0-201.0	198.9 at N53W/50N	Moderate Iron Staining
	5	201.0-206.0		No Water-Bearing Fractures
CECRL14 [247.0-257.0]	1	232.5-237.5	No Orientation Data	No Water-Bearing Fractures
	2	237.5-242.5	240.1 at N55E/38W	Slickensides & Iron Staining
	3	242.5-247.5		No Water-Bearing Fractures
	4	247.5-252.5	248.8 at N66W/50N	Light Iron Staining
	5	252.5-257.5	255.7 at W/32N	Light Iron Staining
CECRL15 [180.3-190.3]	1	168.0-173.0	No Orientation Data	
	2	173.0-178.0	177.1 at N49W/44N	Light Iron Staining
	3	178.0-183.0		No Water-Bearing Fractures
	4	183.0-188.0	183.7 at N48W/40N 184.5 at N72W/43N	Moderate Iron Staining
	5	188.0-193.0	188.8 at N10E/60E	Light Iron Staining
CECRL16 [190.0-200.0]	1	177.5-182.5	No Orientation Data	No Water-Bearing Fractures
	2	182.5-187.5		No Water-Bearing Fractures
	3	187.5-192.5		No Water-Bearing Fractures
	4	192.5-197.5	195.2 at N35E/38E	Major Water-Bearing Zone, (0.3 ft thick). Heavy Staining
	5	197.5-202.5		No Water-Bearing Fractures
CECRL18 [190.0-200.0]	1	176.0-181.0	No Orientation Data	No Water-Bearing Fractures
	2	181.0-186.0	No Orientation Data	No Water-Bearing Fractures
	3	186.0-191.0		No Water-Bearing Fractures
	4	191.0-196.0		No Water-Bearing Fractures
	5	196.0-201.0	198.5 at N50W/44N & N41E/35E	Light Iron Staining Light Iron Staining

Notes:

All depths reported in feet below ground surface





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DATE:

MAR. 1994

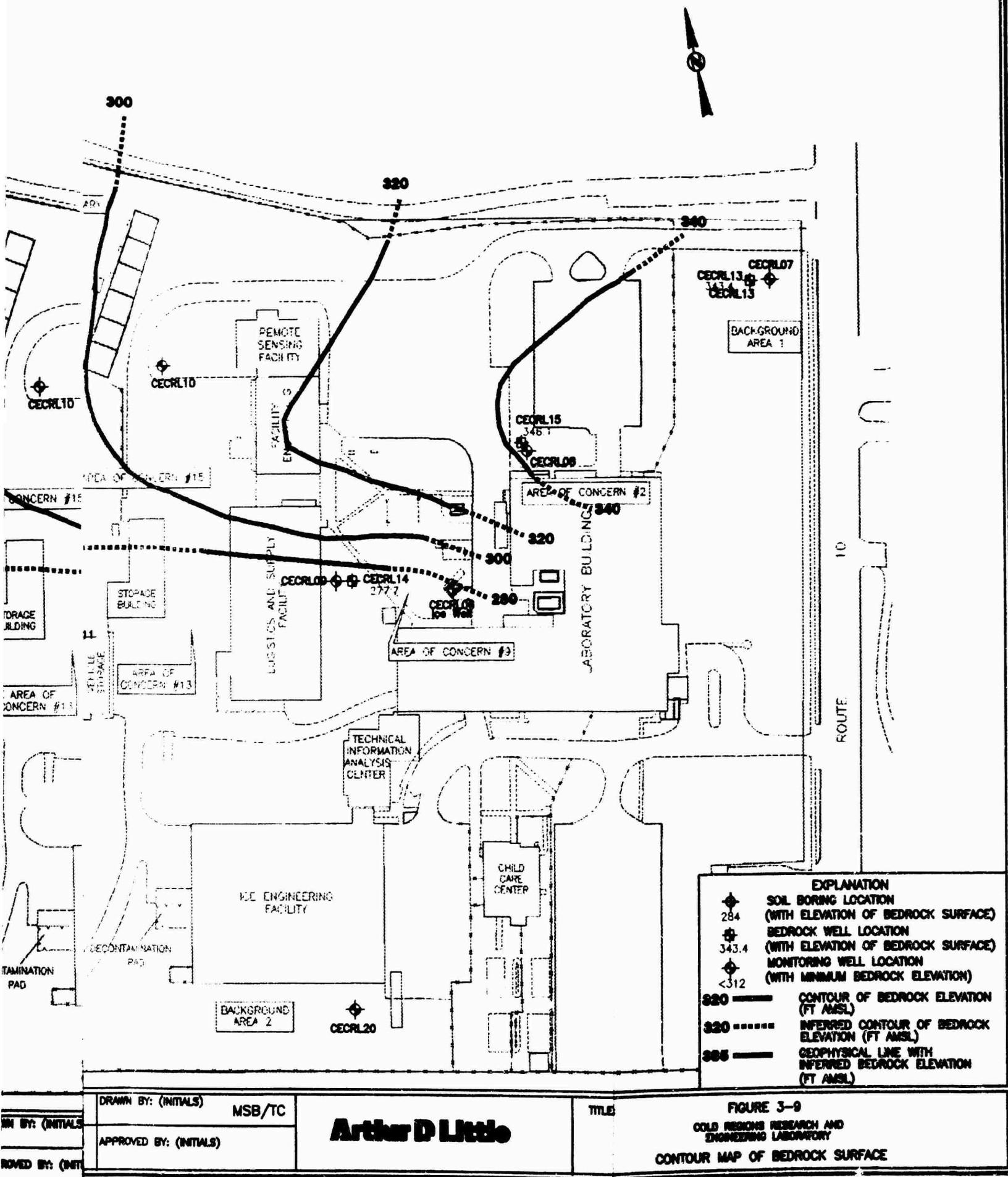
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Arthur D Little

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FIGURE 3-9
COLD REGIONS RESEARCH AND
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CONTOUR MAP OF BEDROCK SURFACE

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and the pond at the southern end of CRREL. The western edge of the bedrock valley trends north-south and is very steep (up to 1.9 feet/foot), reaching a maximum elevation of approximately 400 feet above msl near well CECRL12. The geophysical survey has defined this bedrock ridge as far south as the present location of the Ground Water Treatment Facility, but the total southern extent of the ridge beneath CRREL is not known. The pronounced asymmetry of the valley, produced by both significant differences in gradient and vertical relief between the east and west slopes, was probably formed by Wisconsin glaciation; however, a structural origin (e.g., fault-related) cannot be dismissed.

Between wells CECRL15 and CECRL14, a steep (0.3 feet/foot) southwest dipping slope is projected. Bedrock at CECRL14 is at the lowest elevation (277.7 feet above msl) documented on the site. The origin of this depression may be a kettle hole.

3.5 Soils

As documented by the Connecticut River Basin Coordinating Committee (1970) and the USDA Soil Survey of Grafton County, New Hampshire (1939), the soil types that characterize the CRREL site are of the Hadley-Winoski-Windsor association. These are deep, well-drained, moderately well-drained, and excessively drained soils having silty and sandy textures. CRREL soils, from east to west across the site, consist primarily of the Hitchcock silt loam (8 to 15 percent slope), the Hitchcock silt loam (15 to 60 percent slope), and the Windsor loamy fine sand (15 to 60 percent slope), respectively (USDA, 1939).

The Hitchcock silt loam (15 to 60 percent slope) consists of deep, very well-drained soils that are silty on terrace escarpments along the Connecticut River Valley. Included within this soil are areas of moderately drained Dartmouth soils on narrow benches, poorly drained Binghamville soils on narrow ravine floors and at the base of slopes, and excessively drained soils that occur at the intersection of escarpments and strata of contrasting material (USDA, 1939).

A typical sequence of the Hitchcock silt loam series is as follows:

- 0 to 6 inches: brown silt loam
- 6 to 8 inches: gray silt loam
- 8 to 13 inches: light olive brown silt loam
- 13 to 19 inches: light yellowish brown silt loam
- 19 to 31 inches: grayish-brown silt loam
- 31 to 65 inches: olive gray silt

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The Windsor series consists of very deep, excessively drained soils of glaciofluvial land formations. These formed in glacial outwash deposits of sands and loamy sands derived mainly from crystalline rock. In undisturbed areas, a 2-inch thick, very dark and grayish brown loamy sand surface is often observed. The subsoil of this series from 2 to 20 inches is brown and yellowish brown loamy sand and changes to light yellowish brown sand from 20 to 24 inches. The substratum at a depth of 24 to 65 inches consists of pale brown and light, brownish gray, loose stratified sand (USDA, 1939).

Due to the extensive construction activities at the CRREL site, most of the native soil has either been paved over or reworked by construction crews. As a result, the areas of undisturbed native soil have diminished and it is doubtful that significant sections remain.

3.6 Hydrogeology

This section describes the hydrogeology beneath CRREL and the west side of Connecticut River for the area around the Goodrich and Peacock residential wells. Information on the site hydrogeology is based on the following data:

- Hydrogeologic cross sections across CRREL and vicinity (Figures 3-4 to 3-6)
- Several rounds of ground water measurements from on-site monitoring wells, including monitoring of river-ground water response, and contemporaneous ground water measurements at the Goodrich and Peacock wells by personnel from the State of Vermont
- In situ permeability tests at the on-site monitoring wells

These data aid in defining the major hydrostratigraphic units, determining horizontal and vertical flow direction/gradients, and estimating ground water flow velocities, respectively.

3.6.1 Hydrostratigraphic Units

Figures 3-4 to 3-6 show the occurrence of ground water within the geologic units at CRREL. Across most of the site, the water table is located within the glaciolacustrine units. However, at the western edge of the site, the water table occurs in bedrock. Therefore, with the exception of the lacustrine clay unit (CL), all of the geologic units discussed previously in Section 3.4 occur within the water table aquifer. The hydrostratigraphic units fall into two main categories -- unconsolidated deposits and bedrock.

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Although the unconsolidated and bedrock units are hydrologically connected, there is a significant difference in the manner and rate at which ground water moves in each. Ground water movement through the unconsolidated deposits occurs in the pore space between grains and is considered to be isotropic over short distances. Ground water over most of the site occurs within the fine silty sand (SM) unit and the fine to coarse sand (SP/SW) deposits of the esker. However, beneath the lower terrace access road, overburden ground water also occurs in the fine sand silt (ML) unit.

Ground water movement through the bedrock occurs along discrete fractures, with the net ground water movement determined by aquifer potential. Ground water occurs in the bedrock throughout CRREL.

The lacustrine clay unit (CL) is located above the ground water table, but locally contains perched water, especially on the lower terrace near the northern boundary of the site. Similarly, perched water is also documented in the sandy to clayey silt (SM) at the center of the site along the lower terrace access road. The occurrence of perched water may be due to a combination of several factors, including the presence of a drainage swale along the east side of the access road, leaks in storm sewer lines located along the west side of the access road, or the residual effects of an intermittent stream that was buried during construction. Perched water will eventually migrate to the regional ground water table.

3.6.2 Ground Water Flow Directions and Gradient In Overburden at CRREL

Ground water flow in the water table aquifer was determined from three rounds of measurements (August 23, September 27, and November 29, 1993) at all of the on-site ground water monitoring wells during the Phase II investigation. Table 3-3 shows the elevations of the water table during five rounds of measurements between March 1992 and November 1993. Since all rounds of measurements are similar, the discussion below focuses primarily on data from the September 27, 1993 round of measurements.

Figure 3-10 is a water table contour map based on measurements collected on September 27, 1993. Data used for the construction of this map are from those wells screened closest to the water table. With the exception of CECRL17, these consist of all of the overburden wells (CECRL07 to CECRL11, CECRL19, and CECRL20) and bedrock well CECRL12, as the water table occurs in the bedrock at this location. Overburden well CECRL17 was not used in the construction of the water table contour map because we believe that water levels in this well are affected by perched water infiltration, producing anomalous high water levels at this well. To construct the map we replaced CECRL17 data with data from CECRL16, the adjacent bedrock well. During the September round, the only production wells actively pumping were CECRL01 and CECRL03. This was the most typical pumping scenario at the CRREL well field during the Phase II field investigation.

Table 3-3: Ground Water Elevations - March 1992 to November 1993

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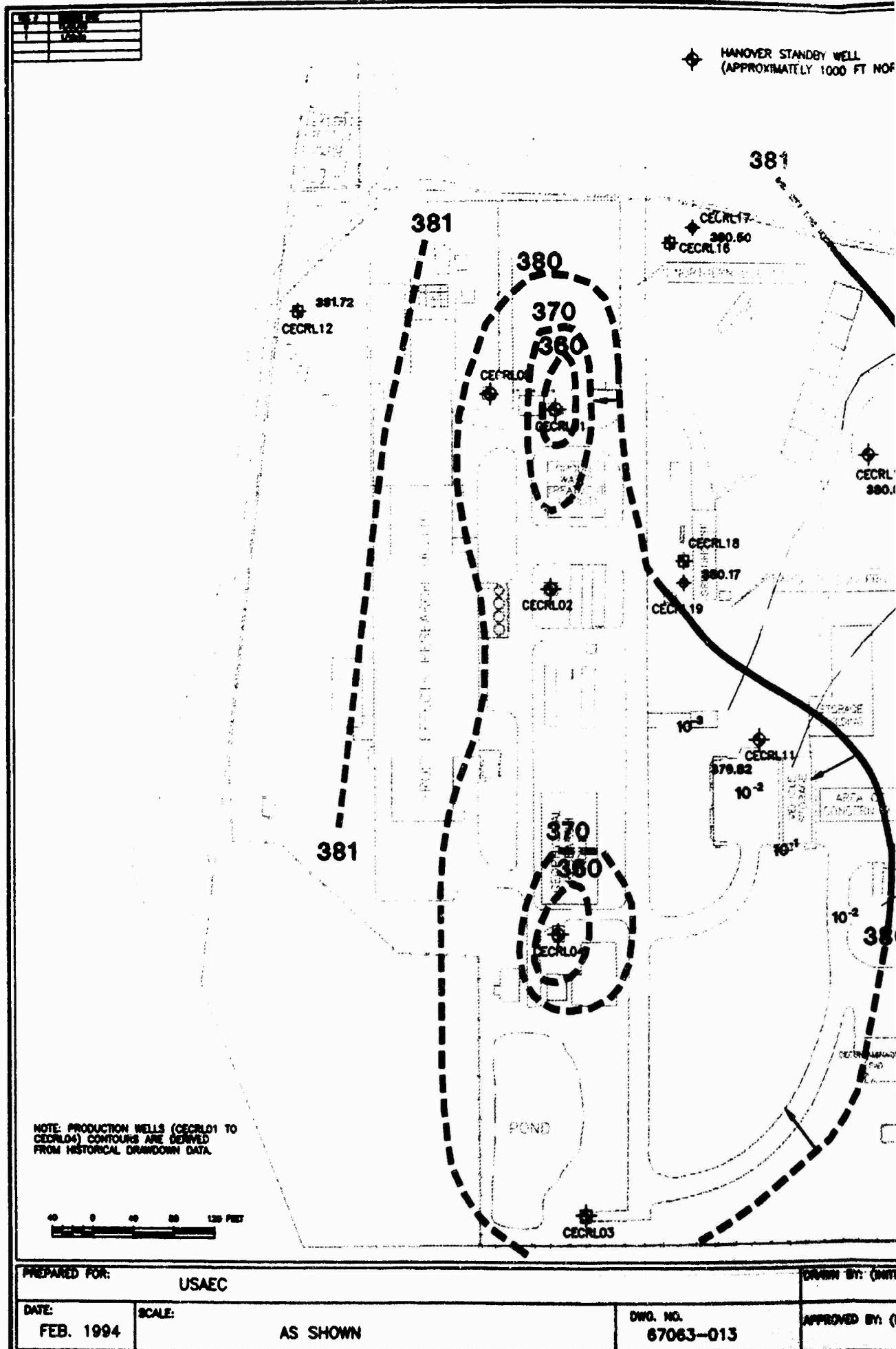
FIT BGS - feet below ground surface

FT MSL - feet mean sea level

- No Data Available

0708301TEP2/reportLn_09.09.09/17/04

HANOVER STANDBY WELL
(APPROXIMATELY 1000 FT NOF)



FT NORTH

STANDBY WELL
APPROXIMATELY 1000 FT NORTH OF CRREL)

CECRL10
380.63

CECRL10
380.63

380

380

10⁻²10⁻³E. ENGINEERING
FACILITY

CECRL20
380.62

382

383

CECRL07
CECRL13
383.62

CECRL12
383.62

383

382

CECRL1
CECRL09
380.70

CECRL08
ICE WELL

381

CHILD
CARL
CENTRE

EXPLANATION	
◆	WATER TABLE MONITORING WELL WITH WATER TABLE ELEVATION
◆	BEDROCK WELL LOCATION
380	CONTOUR OF WATER TABLE SURFACE ELEVATION (DASHED WHERE INFERRED)
10 ⁻²	CONTOUR OF AVERAGE LINEAR GROUND WATER VELOCITY (FT/DAY)
10 ⁻³	DIRECTION/VELOCITY OF GROUND WATER FLOW

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BY: (INITIALS)	
APPROVED BY: (INITIALS)	

Arthur D Little

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FIGURE 3-10
COLD REGIONS RESEARCH AND
ENGINEERING LABORATORY
WATER TABLE CONTOUR MAP, SEPTEMBER 27, 1993

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Across most of CRREL, overburden ground water flow is in the fine-medium grained sand, silty sand, and clay units of the lake sediments, and the medium-coarse grained sand of the esker. Ground water flow in the lake sediments is to the west with progressively decreasing horizontal hydraulic gradients to the west. For the September monitoring round horizontal hydraulic gradients, expressed as a dimensionless ratio, decreased from 0.006 feet per foot (0.006) between CECRL07 and CECRL08 to 0.003 between CECRL09 and CECRL11.

Within the esker, ground water flow is less defined because of the absence of monitoring points, but evidence discussed in detail in Section 3.6.7 strongly suggests radial flow produced by strong production well pumping. Radial flow has produced a capture zone in the esker and adjacent lake sediments. Based on the distribution and concentration of VOCs presented in Section 4.0, it appears the northern portion of the esker is receiving the bulk of ground water flow from the most severely contaminated lake sediments. At the southern portion of the esker, ground water is drawn from a non-contaminated portion of the aquifer, probably to the south of CRREL.

The vertical hydraulic gradient was measured at the five overburden/bedrock well couples to determine if the potential measured indicates discharging or recharging conditions. Table 3-4 shows the vertical hydraulic gradients for wells measured in August, September, and November 1993. The data show that for most of the site, the hydraulic potential decreases downward, indicating that most of the aquifer beneath the center of CRREL is subjected to recharging conditions. Recharging conditions exist between well couplet CECRL16/17 (-0.073 to -0.060) and well couplet CECRL09/14 (-0.005 to -0.003). No direct data exist to determine vertical gradients between the Connecticut River and wells CECRL16/17. East of wells CECRL09/14, the hydraulic potential increases downward, indicating that the eastern part of CRREL is subjected to discharging conditions. The transition between positive and negative vertical hydraulic gradients appears to be in the vicinity of well couplet CECRL08/15, where a negative gradient (-0.083) was documented in August and a positive gradient (0.014 and 0.023) was documented in September and November. Relatively steep positive gradients (0.034, 0.029, and 0.030) are present at well couplet CECRL07/13. The vertical hydraulic gradients are subtle at CRREL and do not constitute a major component of flow, but are very significant when identifying transport mechanisms for potential contaminants.

Where data are available, the majority of the wells show typical seasonal water level fluctuations (Table 3-3). The water table was higher during the spring of 1992 where recharge was enhanced by thawing of snow and ice relative to the comparatively dry summer-fall season of 1993. The single exception is well CECRL12, located west of the CRREL pumping wells and closer to the Connecticut River than all other wells on site. A review of water level data collected at the Wilder Dam, located 4.4 miles

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Table 3-4: Vertical Hydraulic Gradients - August, September, and November 1993

CECRL07	Overburden	174	141.96	142.09	141.79	141.07	0.03
CECRL13	Bedrock	198	141.23	141.39	0.029		
CECRL08	Overburden	141.5	133.68	133.72	133.25		
CECRL15	Bedrock	185.3	137.3	-0.083	133.11	0.014	0.023
CECRL09	Overburden	131.5	129.23	129.05	128.58		
CECRL14	Bedrock	252	129.8	-0.005	129.59	-0.004	
CECRL17	Overburden	98	81.54	83.02	90.87		
CECRL16	Bedrock	195	88.64	88.86	-0.06	88.52	0.024
CECRL19	Overburden	98	87.18	86.55	86.67		
CECRL18	Bedrock	195	88.01	-0.009	87.38	-0.009	-0.006
					87.3		

Notes:
 FT BGS - feet below ground surface
 All vertical hydraulic gradients reported in feet/foot

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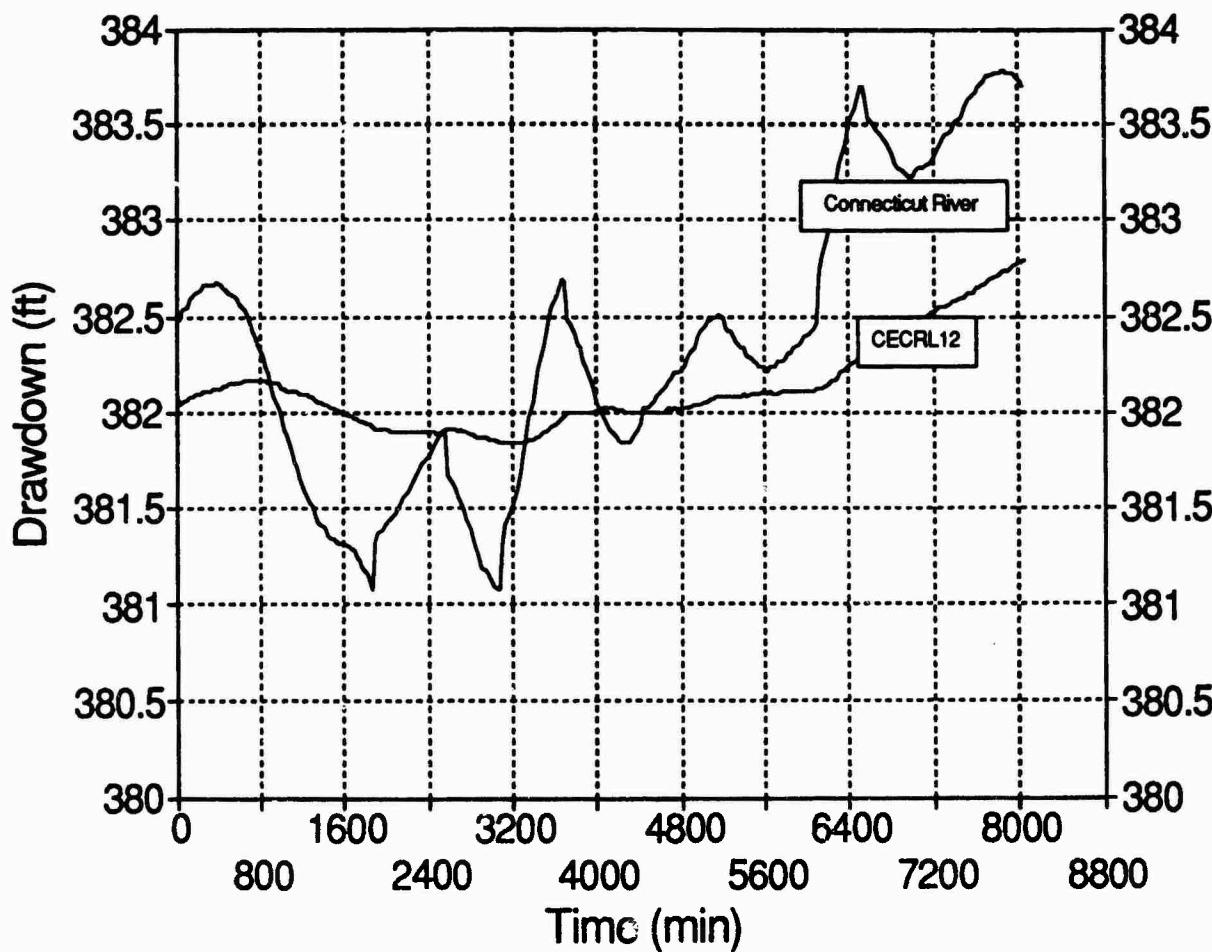
downstream on the Connecticut River, suggests a connection between the observed water level changes in the river and well CECRL12. To test this hypothesis, water level monitoring was conducted simultaneously in the Connecticut River and well CECRL12 for five full days. The results are graphically presented in Figure 3-11. The sharp fluctuation of the river water level of 1 to 2 feet are produced by controlled releases and retention of water at the Wilder Dam. The significantly smaller fluctuations observed in well CECRL12 are clearly in response to the river for two reasons. First, significant changes in water level at CECRL12 follow shortly after significant changes in the river water level, indicating that the water table fluctuates in response to the river. Significant changes in water level trends are present at $t=800$ minutes, $t=3,300$ minutes, $t=4,800$ minutes, and $t=5,600$ minutes. Second, the significant changes in water level in the river and water table occur in the same direction and relative magnitudes, indicating a cause and effect relationship. Calculated lag time between the river and well CECRL12 is consistent with the observations.

In Figure 3-10, the initial datum for the water level (382.5 feet above msl) in the river is reported for the Wilder Dam since no reliable reference elevation for the river is located closer to CRREL. Since the dam is downstream, this value represents a minimum elevation for the Connecticut River near CRREL. Figure 3-10 shows that flow between the river and the water table on the east side of the river alternates. When the water table is higher than the river a discharging setting is created. However, when the river level is higher than the water table, the upper portion of the aquifer is recharged. Under its operating permit, the Wilder Dam can produce water level fluctuations between 380 and 385 feet above msl. Total fluctuation of the Connecticut River during the five days of monitoring was nearly 3 feet. Since the highest water levels reported on the site (CECRL07/CECRL13) are approximately 383.8 feet above msl, it is possible that the entire aquifer beneath the site is affected by the Connecticut River.

3.6.3 Ground Water Gradient and Flow Directions In Bedrock

The elevation of the piezometric surface was measured in the five bedrock monitoring wells that are screened below the water table (CECRL13 to CECRL16, and CECRL18) to determine the general direction of ground water flow in the bedrock. Ground water flow in metamorphic bedrock is heterogeneous and is determined by paths of least resistance through a complex network of fractures. Ground water measurements from September 1993 indicate that the net direction of ground water movement in the bedrock beneath CRREL is toward the west-southwest (Figure 3-12). The horizontal hydraulic gradient is steepest at the northeast part of the site and progressively decreases toward the west.

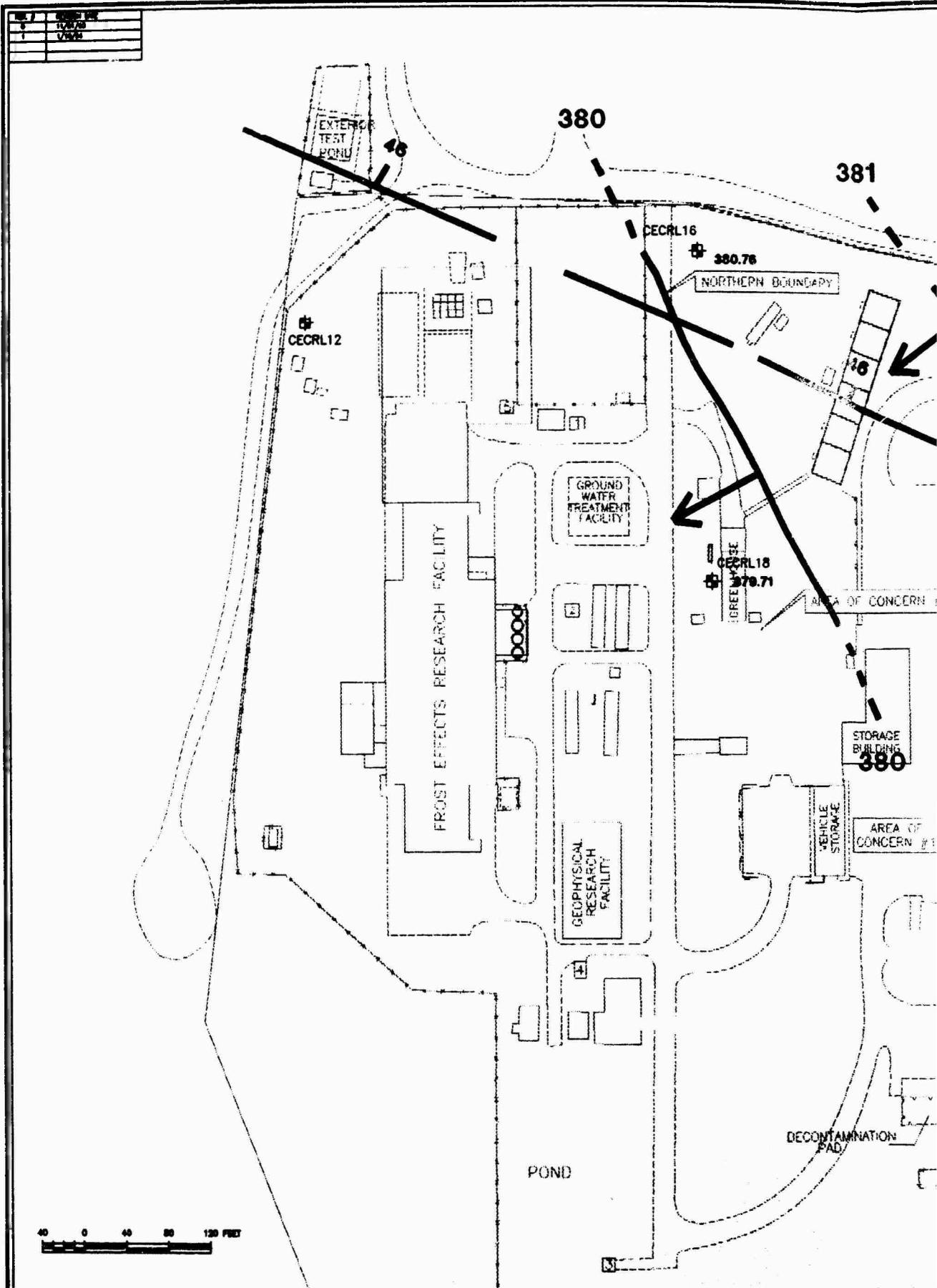
Long-term Monitoring of CECRL12 and the Connecticut River: 10-01-93 to 10-07-93



PREPARED FOR:	
USAEC	
DATE:	DWG. NO.:
FEB. 1994	67063-044

SOURCE: ARTHUR D. LITTLE, INC. FIELD INVESTIGATION, 1993
Arthur D Little

TITLE:
FIGURE 3-11
COLD REGIONS RESEARCH AND
ENGINEERING LABORATORY
LONG-TERM MONITORING AT
THE CONNECTICUT RIVER AND
WELL CECRL12



PREPARED FOR:
USAEC

DRAWN BY: (INITIALS)

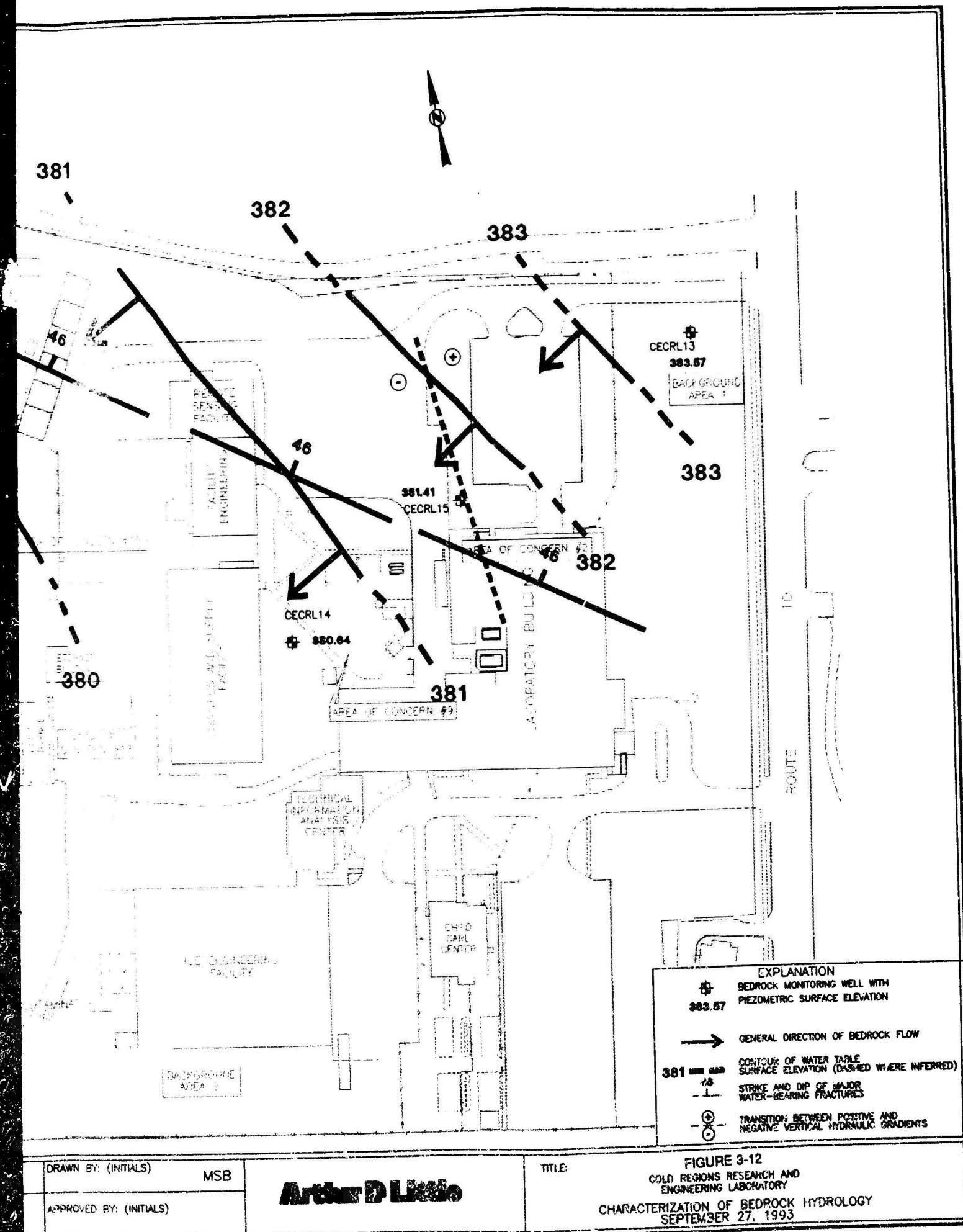
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Actual ground water flow most likely occurs along fracture planes in the direction of lower hydraulic potentials. As described in Section 3.4.2.1, the dominant orientation of water-bearing fractures is N53W, dipping at 46° to the east. Since the net ground water flow direction and the orientation of the water-bearing fractures are subparallel, a strong case is presented for westerly (and some easterly) flow of ground water in the bedrock. While the northeasterly dip direction of the fracture plane will not prevent the ultimate movement of ground water to the west, it may provide a secondary directional vector for the preferential movement of contaminants.

The fields of positive (discharging conditions) and negative (recharging conditions) vertical hydraulic gradients are shown in Figure 3-12. As previously discussed, small negative gradients exist over all of CRREL west of CECRL15. East of CECRL15 small positive gradients are documented. The relevance of these gradients to the bedrock portion of the aquifer is that there is no natural impedance for discharging conditions to exist in the bedrock over most of the site, and, therefore, ground water that reaches the bedrock remains in the bedrock at least as far west as the Connecticut River.

3.6.4 Ground Water Flow Directions on the West Side of the Connecticut River
In 1993, a study of the characteristics of the bedrock aquifer on the west side of the Connecticut River was conducted for VTDEC by The Johnson Company. The work included an investigation of the bedrock geology through drilling, geophysical logging, fracture trace analysis, and outcrop study. In addition, a pump test was performed on the Goodrich well. The report concluded that there were two distinct bedrock ground water regimes, one within 1 to 2,000 feet of the river, and the other greater than 2,000 feet from the river. The regime closest to the river is of greatest importance to this investigation, and is described below.

The bedrock aquifer closest to the river is characterized by having a relatively low horizontal gradient (0.02 ft/ft) and a vertical gradient that fluctuates between upward and downward. The vertical gradient between bedrock and surficial aquifer is also variable but can maintain a downward gradient for at least several days at a time. Water levels in the bedrock aquifer respond to changes in the river level with a very short time lag, similar to that observed at CRREL. The direction of ground water flow in the bedrock is southeast toward the river.

The RI did not include any sample collection or ground water measurements from wells on the west side of the river. However, in cooperation with the RI effort, VTDEC personnel collected water level measurements in wells across the river on the same day that water level measurements were taken in the CRREL wells. Analysis of this data revealed that two of the bedrock wells on the west side of the river (Peacock and MW-1B) consistently showed potentiometric surfaces higher than the potentiometric surfaces in all the bedrock wells at CRREL. The Goodrich well,

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which is immediately adjacent to MW-1B, showed potentiometric surface measurements within the range of those observed at CRREL. It should be noted, however, that the elevation of the Goodrich well was estimated from the topographic map, and has not been surveyed, and there is some discrepancy in the depth to top of casing from ground surface (VTDEC uses -1.9 feet and The Johnson Company uses -1.4 feet). Analysis of the ground water level data indicates that ground water in the bedrock aquifer on the west side of the river appears to flow toward the river.

3.6.5 In Situ Hydraulic Conductivity Results

During the in situ hydraulic conductivity testing performed at the CRREL site, all overburden and bedrock wells were subject to analyses. After slug testing the wells in accordance with the methodology described in Section 2.5.3, the data were downloaded to a PC compatible computer so that computer-aided evaluation could be employed. This evaluation of the slug testing data was achieved by implementing the Bouwer and Rice (1989) method of interpretation. As this interpretation method has compensating parameters for testing unconfined aquifers, wells that are screened in the water table, and sand pack irregularities, it projected the most accurate estimate of hydraulic conductivity for the CRREL site. Appendix J provides raw data and graphs of in situ hydraulic conductivity tests.

At CRREL, hydraulic conductivities measured throughout the area ranged from 3.39×10^{-4} ft/sec to 1.99×10^{-8} ft/sec using the Bouwer and Rice method (1989). Table 3-5 reflects a summary of the CRREL hydraulic conductivity values and the materials that influence their rates.

The bedrock wells yielded two sets of conductivity ranges, one set indicating highly fractured bedrock and the other poorly fractured bedrock. Conductivities measured in CECRL14 and CECRL18 provided the slowest values obtained on the site. CECRL14 exhibited the upper limit of this range with a reading of 1.99×10^{-8} ft/sec value for a rising head test and CECRL18 yielded similar results with rising and falling head test values lying in the 10^{-7} to 10^{-8} ft/sec range. These values are in direct conjunction with the estimated hydraulic conductivities for poorly fractured to unfractured bedrock, which lie between 10^{-8} and 10^{-12} ft/sec, with 10^{-12} ft/sec representing unfractured metamorphic and igneous rocks (Freeze and Cherry, 1979). Moreover, these values were consistent with the slow recharge rates observed during ground water purging and the lack of fractures found during coring. The values found at CECRL12 and CECRL13 yielded a range of 4.36×10^{-5} ft/sec to 7.79×10^{-6} ft/sec. These values fell into the expected range of hydraulic conductivities for fractured metamorphic bedrock and this indication is supported by the steady recharge rates during purging and the moderately to highly fractured bedrock observed during coring.

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Table 3-5: Values of Hydraulic Conductivity From In Situ Permeability Tests

Number	Test Type	Depth FT BGS	Material	Conductivity FT/DAY	Notes
CECRL07	Falling Head Rising Head	354.0-344.0	SM	1.9E-05 4.07E-06	
CECRL08	Falling Head Rising Head	376.2-366.2	SP	1.53E-04 3.41E-04	
CECRL09	Falling Head Rising Head	380.7-370.7	SP	5.54E-05 1.87E-04	
CECRL10	Falling Head Rising Head	376.1-366.1	SM	2.72E-05 1.40E-05	
CECRL11	Falling Head Rising Head	370.0-360.0	SP	1.91E-06 1.46E-06	
CECRL12	Falling Head Rising Head	389.8-369.8	Bedrock	4.36E-05 6.59E-05	
CECRL13	Falling Head Rising Head	330.0-320.0	Bedrock	7.79E-06 5.57E-06	
CECRL14	Falling Head Rising Head	261.7-251.7	Bedrock	- 1.99E-08	No Aquifer Response
CECRL15	Falling Head Rising Head	332.3-322.3	Bedrock	-	No Aquifer Response
CECRL16	Falling Head Rising Head	277.0-267.0	Bedrock	-	Rapid Recharge
CECRL17	Falling Head Rising Head	379.1-359.1	ML	3.80E-06 3.67E-07	
CECRL18	Falling Head Rising Head	275.1-265.1	Bedrock	1.17E-08 1.72E-07	
CECRL19	Falling Head Rising Head	377.0-357.0	SM/ML	2.65E-06 2.62E-06	
CECRL20	Falling Head Rising Head	367.3-357.3	SW	1.37E-04 3.39E-04	

Notes:

All values calculated using the Bower & Rice Method

FT BGS feet below ground surface

SM silty sands

SP poorly graded sands/gravelly sands

ML clayey silts/silty or clayey fine sands

SW sandy gravel

Arthur D. Little

In testing the overburden wells that were screened in clean sand (CECRL08, CECRL09, CECRL11, and CECRL20), the hydraulic conductivities ranged from 1.37×10^{-4} ft/sec to 1.91×10^{-6} ft/sec. The wells that were screened in silts, silty sands, and clayey silts yielded conductivities ranging from 1.46×10^{-5} ft/sec to 3.67×10^{-7} ft/sec. Both ranges were consistent with the projected values for the particular sediment type. Furthermore, the slow pumping rates for the wells screened in the silt materials compared to the quick rates of the other overburden wells reinforces the validity of the data.

With the exception of CECRL16 (see Section 2.5.3), all wells were tested for hydraulic conductivity by employing a rising head and falling head test procedure. CECRL16 was not tested due to the well construction and the extremely high recharge rate observed during purging. Due to the slow recharge of CECRL14, only a rising head test could be performed and the hydraulic conductivity was derived from the single test on this well. Well CECRL15 showed insufficient aquifer response to slug testing.

All hydraulic conductivities for falling head tests coincide in values to their respective rising head test, with the largest deviation between a pair being less than an order of magnitude. All other quality control data indicate that the tests were representative of actual conditions.

3.6.6 Ground Water Velocity

The rate of ground water flow in the overburden at CRREL was estimated using the Dupuit equation, which is a function of hydraulic conductivity data from the overburden monitoring wells, the saturated thickness of the overburden, and the horizontal hydraulic gradient. The velocity calculations are for a unit volume of water from the water table to the bedrock surface, and assume steady flow in an unconfined aquifer. Based on hydraulic conductivity data from the slug tests, total ground water flow through the bedrock is considered minor compared to the overburden and was, therefore, discounted from these calculations.

Contours of ground water velocities for the September 27, 1993, water table measurements are shown on Figure 3-10. Velocities across the site range from 10^{-1} to 10^{-3} feet/day, depending on the hydrostratigraphic media. The highest velocities appear to be located in the center of CRREL. This area of comparatively high velocity has an elliptical geometry that is elongated in a northeast-southwest direction and occurs beneath AOCs 1, 2, 3, 4, 9, and 13. Flow velocities appear to decrease away from this zone as lower horizontal hydraulic gradients are encountered to the southeast and lower hydraulic conductivities are encountered to the northwest. The low velocities (10^{-3} feet/day) calculated for the northwest corner of CRREL only approximate the uppermost region of the aquifer. Unlike the remainder of the site, where the hydraulic conductivity data are generally representative of the entire

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hydrostratigraphic column for each location, geologic borings indicate that an upper clayey silt unit (ML) and a lower fine- to coarse-grained sand unit (SP/SW) comprise the overburden aquifer beneath the vicinity of the lower terrace access road.

3.6.7 Effects of Well Field Pumping

This section provides an assessment of the influence of well field pumping on the esker and lake sediment units. The assessment is based on a review of limited historical water level data from the production wells; water level data from monitoring wells and the Connecticut River; pumping data from 1993; and a consideration of bedrock topography, esker morphology, and pumping test data. Figure 3-10 shows the inferred ground water contour lines around the well field, based on recent and historical ground water measurements. Table 3-6 summarizes well field pumping during the Phase II RI and summarizes historical ground water measurements from the production wells.

The well field at CRREL consists of five production wells (CECRL01 through CECRL05) that are screened entirely within medium- to coarse-grained esker sand beneath the lower terrace of the site. Based on pumping data collected from August 1 to December 31, 1993, the total yield of the well field was 190,861,700 gallons. During this time, the majority of the ground water was pumped from wells CECRL01 and CECRL03, with totals of 44.3 percent and 35.1 percent of the well field yield, respectively. The remaining 20.6 percent of production water was withdrawn from wells CECRL04 (8.9 percent), CECRL02 (11 percent), and CECRL05 (0.7 percent), which operated intermittently during the period. Well CECRL03 had the highest pumping rate, ranging between 662 and 727 gallons per minute (gpm). In comparison, CECRL01 pumped between 459 and 504 gpm. The maximum total well field pumping rate was approximately 1,756 gpm when all wells but CECRL05 were active. However, a more typical rate for the well field was 1,183 gpm when only wells CECRL01 and CECRL03 were operating. These data indicate that there were two focal points of stress on the aquifer within the esker during the Phase II investigation -- the southern portion of the esker between wells CECRL03 and CECRL04, and the northern portion of the esker at CECRL01.

As Figure 3-10 indicates, pumping-induced stress on the aquifer has historically created significant drawdown in the vicinity of pumping wells. For example, data reported in the Phase I RI (Ecology and Environment, 1992) and data from 1988 (Gatto and Shoop, 1991) shows over 20 feet of drawdown at wells CECRL01 and CECRL04 under pumping conditions. Similar amounts of drawdown may be expected from the other wells in the esker under similar pumping conditions. Under non-pumping conditions the water level in well CECRL02 was measured at 380.3 feet above msl -- a level that is comparable to those measured at wells screened in the lake sediments immediately to the east of the lower terrace access road (CECRL11 and CECRL19) during the Phase II RI.

Table 3-6 : 1993 Pumping Data and Historical Water Level Measurements From CRREL Production Well Field

Well Number	Phase I RI Data			1988			1986		
	1993 Pumping Date	Elevation of Ground Surface	Depth To Water FT BGS	Ground Water Elevation FT MSL	Depth To Water FT BGS	Ground Water Elevation FT MSL	Depth To Water FT BGS	Ground Water Elevation FT MSL	Depth To Water FT BGS
CECRL01	44.3	459 - 504	467.2 [462.4]	88 *379.2 [Non-Pumping] 110 *357.2 [Pumping] 380.3 [Non-Pumping]	--	--	--	--	--
CECRL02	11.0	404 - 493	468.5 [462.1]	--	--	--	--	--	--
CECRL03	35.1	662 - 727	462.6	--	--	--	--	--	--
CECRL04	8.9	130 - 178	465.9	--	--	--	91 374.9 [Non-Pumping] 107 358.9 [Pumping]	81.3 381.3 [Pumping CECRL01]	100 368 [Pumping CECRL01]
CECRL05	0.7	233 - 333	465.9	--	--	--	--	--	--

Notes:

FT BGS - feet below ground surface
 FT MSL - feet mean sea level

- No Data Available

*Anecdotal evidence in Phase I RI. Data not collected during Phase I investigation

- Ground surface surveyed in March 1991. [] indicate original ground surface

- 1993 Pumping Data is from August 1 to December 31. During this period 190,861,700 gallons of water were removed from the system.

- 'Non-Pumping' conditions do not preclude the pumping of nearby wells and are not equatable to regional 'static' conditions

Source: Gatto and Shoop (1991) and Ecology and Environment (1992)

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The effects of current well field pumping on the CRREL site are assessed by considering the aspects of the following features of the esker setting:

- Local bedrock topography
- Esker morphology
- Inferences from the Town of Norwich, Vermont, pumping test

3.6.7.1 Local Bedrock Topography. As stated in Section 3.4.2.2, the esker rests on a steeply dipping bedrock slope west of the production well. At some location between production well CECRL05 and monitoring well CECRL12, the bedrock ridge rises above the water table. This location marks a distinct east-to-west transition between isotropic ground water flow in the high permeability/porosity esker sand to fractured ground water flow in the bedrock. While the local bedrock is not impermeable, and in some instances contains major water-bearing fractures, on a per-unit area basis it is a poor medium for ground water flow. Therefore, this bedrock high located between the esker sand and the Connecticut River may provide a local barrier to significant local esker recharge from the river. The greatest influence for esker recharge is the intersection of the river with the esker, to the north of CRREL.

3.6.7.2 Esker Morphology. The morphology of the esker is a central consideration in predicting the general orientation of pumping-induced cones of influence. The esker trends north-northeast across the lower terrace of the site. The western part of the esker abuts comparatively impermeable fractured bedrock. To the east the esker abuts fine-medium sand, silty sand, silt, and clay lake sediments. Pumping of ground water at the production wells will induce the most flow in the direction of least stress. Since more energy is required to pull an equivalent amount of water from either fractured bedrock or lake sediments than the esker sand, pumping-induced cones of depression are predicted to be in a north-south orientation. The north-south orientation of the cone of depression is also predicted from the north-south alignment of pumping wells in the esker.

In situ permeability tests indicated significantly greater flow potential through the lake sediments than the bedrock. Therefore, more pump-induced flow from the lake sediments than the bedrock is predicted from the northern pumping wells (especially from CECRL01) where the bedrock ridge was documented.

3.6.7.3 Inferences from the Town of Norwich, Vermont, Pumping Test. The pumping test at the Town of Norwich, Vermont, supply well provides some analogous pumping conditions and a basis for comparison to conditions at the CRREL well field, as the supply well is also screened in the esker. Pumping of the supply well and an observation well at a combined rate of 975 gpm locally produced a drawdown of 3.44 feet (Ecology and Environment, 1992). This is slightly lower

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than the typical well field yield at CRREL of 1,183 gpm during summer-winter, 1993. Gatto and Shoop (1991) report that even at this pumping rate hydraulic gradients were very low -- on the order of 0.001 -- in the esker. The radial cone of influence produced by the supply well was approximately 300 feet parallel to the axis of the esker. However, it was estimated that at least 80 percent of the water pumped during the test was due to recharge from the Connecticut River (Caswell, 1990).

Based on the results of the Norwich well pumping test, the hydraulic conductivity of the esker is 1.48×10^{-1} cm/sec. This is within the published range of K-values for sediment types present within the esker, and suggests that the esker is a highly permeable aquifer unit. The average bulk transmissivity for the esker is 275,000 gallons per day/foot.

The cone of influence from the CRREL well field production may be greater than that documented for the Norwich well under similar pumping capacity conditions. First, the specific capacity of the esker at the Norwich supply well appears to be greater than the esker at CRREL, suggesting that the cone of influence produced by the CRREL well field must be larger to accommodate the documented summer-winter 1993 yield. The specific capacity at the Norwich supply well is approximately 300 gpm/foot (Gatto and Shoop, 1991). Based on drawdown and pumping rate data from CECRL01 and CECRL04, specific capacities from the esker at CRREL may range from 23 to 6 gpm/foot, respectively. Second, unlike the Norwich supply well, which draws a significant (if not most) of its water from river infiltration, the CRREL well field is partially blocked from direct river recharge by a bedrock ridge at the northwest part of the site. Data collected for this report (Section 3.6.2) shows that while bedrock well CECRL12 is in direct communication with the Connecticut River, no influence on CECRL12 by CECRL01, located only 265 feet to the east, can be demonstrated. The greater the lateral extent of the north-south bedrock ridge, the greater the impedance for the production wells to preferentially pull ground water from the lake sediments to the east of the esker.

Regardless of the current eastern extent of the pumping wells' cone of influence, ground water level measurements indicate westerly ground water flow in the overburden across the site and the eventual capture of most (if not all) of the overburden ground water. Repeated ground water measurements have shown a reduction in horizontal flow from east to west across the lake sediments. While this trend would not be predicted if the cone of influence extended to the eastern boundary of the site, this trend correlates with a westward increase in finer and more silt-laden material at the water table, which may mask the effects of pumping influence (Figure 3-10).

3.6.8 Summary

Results of the investigations indicated the following characteristics of the site:

- CRREL is underlain by a single aquifer (an unconfined water table aquifer) that includes portions of the overburden and bedrock. Most of the overburden portion of the aquifer is located in silty sand (SM) of lacustrine origin, but beneath the lower terrace, the aquifer also saturates lacustrine silt (ML) and fluvial-esker sand (SP/SW) units. At the western border of the site, the water table is in bedrock.
- Perched water occurs in the silty clay (CL) and ML units along the lower terrace access road beginning at depth ranging from 13 to 23 feet below grade.
- Ground water flow in the overburden is westward across the site to the esker.
- Current pumping conditions are stressing the northern and southern part of the esker aquifer at CECRL01 and CECRL03, respectively. The presence of a bedrock ridge between the Connecticut River and the esker enhances pumping-induced withdrawal of water from the lake sediments to the east of the esker.
- Ground water flow in the bedrock is generally to the west following the orientation of water-bearing fractures (N53W/46E) and progressively lower hydraulic potentials.
- Vertical hydraulic gradients are negative over most of CRREL, except for the northeast corner, indicating that the bedrock is being recharged by the overburden. The transition between positive and negative gradients occurs near wells CECRL08/15.
- Hydraulic conductivities range from 10^{-4} to 10^{-7} ft/sec in the overburden and 10^{-6} to 10^{-8} ft/sec in the bedrock. Based on these data, the saturated thickness of the overburden, and the horizontal hydraulic gradient, ground water velocities are estimated to be between 10^{-1} and 10^{-3} ft/day. The highest velocities are located near the center of the site while the slowest velocities occur at the northwest part of the site.

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4.0 Nature and Extent of Contamination

This section describes the nature and extent of contamination, based on samples of sediment, surface water, soil, and ground water collected as part of the RI. Data collected from the Phase I and Phase II investigations are used. In addition, the ground water data from the five production wells (CECRL01 through CECRL05) and the Ice Well (CECRL06) collected during USAEC (formerly the U.S. Army Toxic and Hazardous Materials Agency) sampling are included in this section. Since some of the AOCs identified at CRREL may be point sources of contamination to soil, the analytical results for soil samples are discussed separately for each AOC. Ground water is treated as a single continuous medium, and the analytical results are discussed on a sitewide basis.

Tables and figures included in this section describe the detected compounds. A complete listing of the analytical results is presented in table format for each medium in Appendices M, N, and O. Since all of the parameters tested (VOCs, BTEX, and TPH) for each medium are not considered to be naturally occurring compounds in the soil or water, the detectable concentrations are presumed to be the result of site-related activities, with the exception of those compounds that are interpreted to be laboratory contaminants. Section 2.6 provides an analysis of the field and laboratory Quality Control samples.

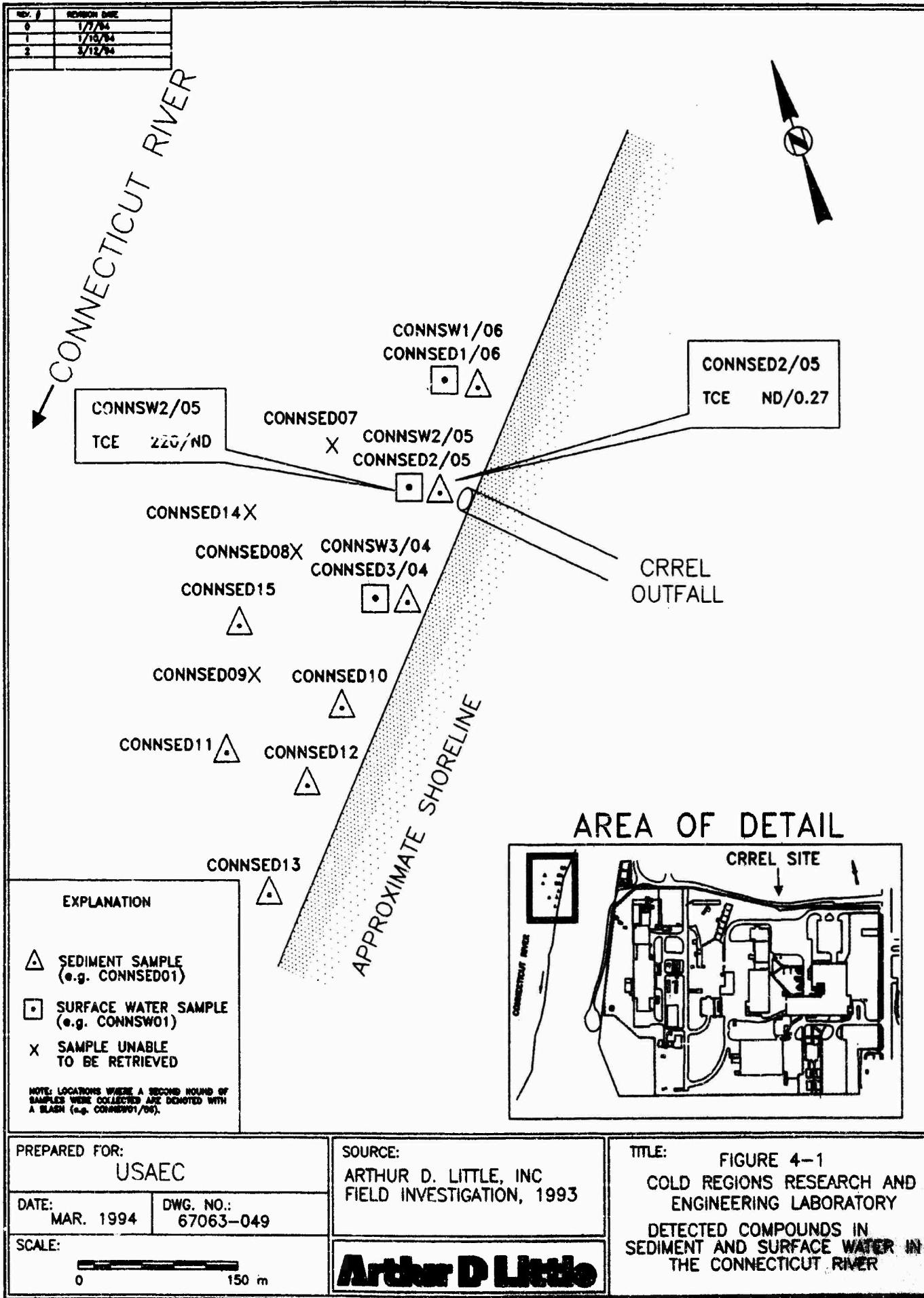
In the discussion of contaminant concentrations, the unit used to describe soil concentrations, micrograms per gram ($\mu\text{g/g}$), is equivalent to parts per million (ppm). The concentration of contaminants in water is expressed as micrograms per liter ($\mu\text{g/L}$), which is equivalent to parts per billion (ppb).

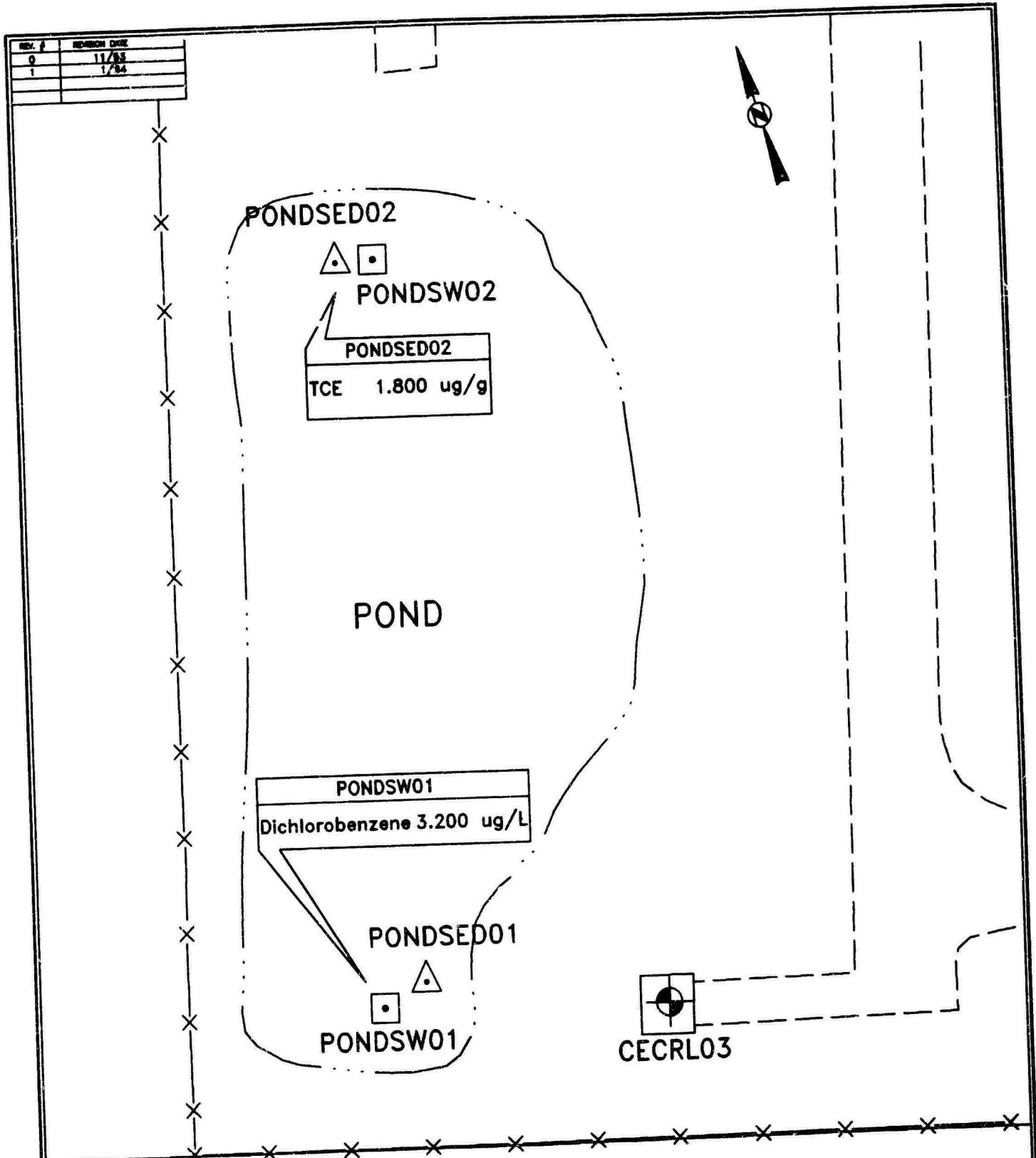
4.1 Sediment and Surface Water

Samples were collected from the sediment and surface water of the Connecticut River and CRREL pond. In general, water samples were taken at the same locations as the sediment samples. Tables 4-1 through 4-4 summarize the detected compounds in the sediment and surface water samples.

4.1.1 Sediment

In order to assess the nature and extent of contamination in sediments related to CRREL, a total of 22 samples were collected from 8 locations at the Connecticut River and 2 locations at CRREL pond. Figures 4-1 and 4-2 are maps indicating sample locations and detected concentrations.





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DATE:
JAN., 1994

DWG. NO.:
67073-031

SCALE:

0 50 FT.

LEGEND

- SURFACE WATER LOCATION
- SEDIMENT LOCATION
- MONITORING WELL LOCATION

TITLE:

FIGURE 4-2
COLD REGIONS RESEARCH AND
ENGINEERING LABORATORY
DETECTED COMPOUNDS IN SEDIMENT
AND SURFACE WATER IN
THE CRREL POND

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Table 4-1: Detected Compounds in Connecticut River Sediments

Site Type Location (S) Collection Date	Sample 1 Depth 0-10 10-20 cm	Sample 2 Depth 0-10 10-20 cm	Sample 3 Depth 0-10 10-20 cm	Sample 4 Depth 0-10 10-20 cm
VOLATILE ORGANIC COMPOUNDS (ug/g)				
HALOGENATED ORGANICS				
Methylene Chloride	0.0080	0.0080	0.0080	0.27
Trichloroethane	-	-	-	-

Notes:

- indicates not detected or less than detection limit

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Table 4-2: Detected Compounds In CRREL Pond Sediments

Site ID: 340 Type: Sample Depth (m) Collection Date:	HANCOCK POND 1-00000	MORSEWOOD POND 01-Det-93
VOLATILE ORGANIC COMPOUNDS (ug/g)		
HALOGENATED ORGANICS Trichloroethene	-	1.8

Notes:
- indicates not detected or less than detection limit

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Table 4-3: Detected Compounds In Connecticut River Surface Water

Site ID Site Type Sample Depth (ft) Collection Date GC Type	CRREL Date (8) 10-Apr-93	CDI Date (8) 09-Apr-93	OC Date (8) 09-Apr-93	OC Date (8) 10-Apr-93	CDI Date (8) 10-Apr-93
VOLATILE ORGANIC COMPOUNDS (ug/L)					
HALOGENATED ORGANICS					
Methylene Chloride	—	6.4	5.0	5.0	5.2
Trichloroethene	300 (360)	—	220	200	—

Notes:

— Indicates not detected or below detection limits

() Indicates analytes detected by analytical method UG05 - halocarbons in water by GC/CON
 OTFL - Sample collected from the Conn. River at the CRREL outfall location

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Table 4-4: Detected Compounds in CRREL Pond Surface Water

Sample ID Sample Type Sample Depth (ft) Collection Date	Method 1 11-02-93	Method 2 11-02-93
VOLATILE ORGANIC COMPOUNDS (ug/L)		
CHLORINATED AROMATICS Dichlorobenzene, nonspecific	3.2	-

Notes:
- indicates not detected or less than detection limit

CRREL: RI Report
Section No.: 4.0
Revision No.: 1
Date: March 18, 1994

4.1.1.1 Connecticut River. Three rounds of sediment samples were collected from the Connecticut River. All samples were analyzed for VOCs and TPH. The second and third rounds of samples (CONNSED04 through CONNSED15) were also analyzed for BTEX. In the VOC analysis of CONNSED05, TCE was detected at a concentration of 0.27 µg/g. CONNSED05 was collected from sediment below the outfall during the third round of sampling. All other samples did not indicate VOC, TPH, or BTEX contamination. Methylene chloride, a suspected laboratory contaminant, was detected in all samples collected during the first round, with concentrations ranging from 0.0080 to 0.0090 µg/g.

4.1.1.2 CRREL Pond. One round of sediment samples was collected from CRREL pond and analyzed for VOCs, BTEX, and TPH. PONDSED01 was collected from the southwest corner of the pond and PONDSED02 was collected from the northeast corner, as depicted on Figure 4-2. In the VOC analyses of PONDSED02, TCE was detected at a concentration of 1.8 µg/g. No other analytes were detected.

4.1.2 Surface Water

Surface water samples were collected from the Connecticut River and CRREL pond so that the nature and extent of surface water contamination could be assessed. Figures 4-1 and 4-2 are maps indicating sample locations and detected compounds. Tables 4-3 and 4-4 summarize the results of the surface water sample analyses.

4.1.2.1 Connecticut River. Two full rounds of surface water samples were taken from the Connecticut River during the RI, preceded by a preliminary round during USAEC sampling. In the preliminary round, samples were taken from the outfall and only analyzed for VOCs. For the two full rounds, samples were collected from 100 feet upstream of the outfall, 100 feet downstream of the outfall, and at the outfall itself. The samples collected from the first round were analyzed for VOCs and TPH. The second round of samples were also analyzed for BTEX. CONNSW2 was taken at the outfall during round one in April 1992, prior to the installation of the ground water treatment system. It was the only surface water sample that exhibited VOC contamination. TCE was detected at a concentration of 220 µg/L in this sample, which is comparable to the USAEC sampling result of 200 µg/L at the same location. CONNSW05 was collected from the outfall after the installation of the ground water treatment system, and revealed no detectable VOCs. CONNSW1 and CONNSW04 were collected 100 feet upstream of the outfall and CONNSW3 and CONNSW06 were collected 100 feet downstream of the outfall. No concentrations of VOCs were detected at these locations. TPH analyses of all samples collected yielded no detections.

Methylene chloride, a suspected laboratory contaminant, was detected in all round one samples at concentrations ranging from 5.0 to 6.4 µg/L.

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Revision No.: 1
Date: March 18, 1994

4.1.2.2 CRREL Pond. One round of surface water samples was collected from CRREL pond and analyzed for TPH, BTEX, and VOCs. PONDSW01 was collected from the lower southwest perimeter of the pond while PONDSW02 was collected from the northeast corner. PONDSW01 yielded 3.2 µg/L of dichlorobenzene. All other analyses yielded no detections.

4.2 Surface Soils

A total of 37 surface soil samples (SSS01 through SSS37) were collected at CRREL during the soil investigation program. These samples were analyzed for VOCs, TPH, and BTEX. Table 4-5 and Figure 4-3 summarize the results of the surface soil sample analyses.

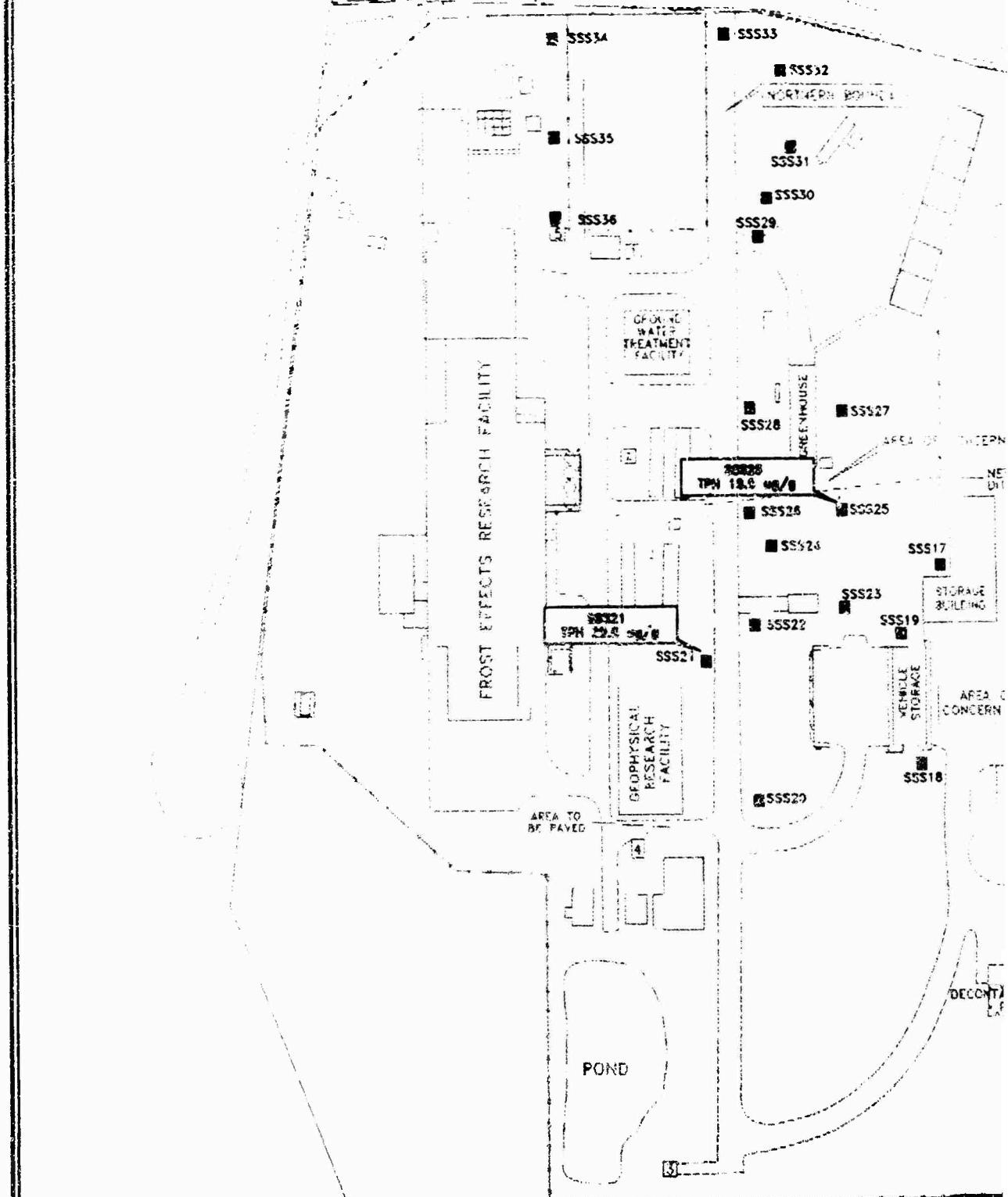
TCE was detected in SSS07 at an estimated concentration of 120. µg/g (see Section 2.6 for a discussion of the use of estimated values.) This sample was collected along the northern perimeter of the Ice Well. SSS37 yielded 0.75 µg/g of 1,1,1-trichloroethane. This sample was taken from the upper terrace near AOC 9 and immediately adjacent to a fuel oil tank and an oil and water tank. The remaining 35 samples exhibited no detections of VOC contamination.

TPH analyses indicated detections at eight locations. These concentrations ranged from 13 to 33 µg/g, with one sample (SSS07) from outside the Ice Well building showing an outlying concentration of 320 µg/g.

BTEX was not detected in the 37 surface soil samples collected.

4.3 Soil Vapor

The Petrex^(R) soil samplers installed at CRREL for the Phase I and Phase II RI were analyzed at the NERI laboratory in Lakewood, Colorado. The analyses performed with an Extrel C-50 Quadropole Mass Spectrometer equipped with a Curie-point Pyrolysis/Thermal Desorption inlet allowed for flux maps of each detected compound to be generated (Section 2.4.3). In the Phase I investigation, flux maps were generated for PCE, TCE, BTEX, and fuel oil character (cycloalkenes/dienes/alkynes and cycloalkanes/alkenes). In the Phase II investigation, flux maps were generated for PCE, TCE, BTEX, and cycloalkanes/alkenes. The NERI soil vapor surveys prepared for the Phase I and Phase II investigations included flux maps for all detected compounds (Appendix P).



1000000000

MSAFC

DATE:

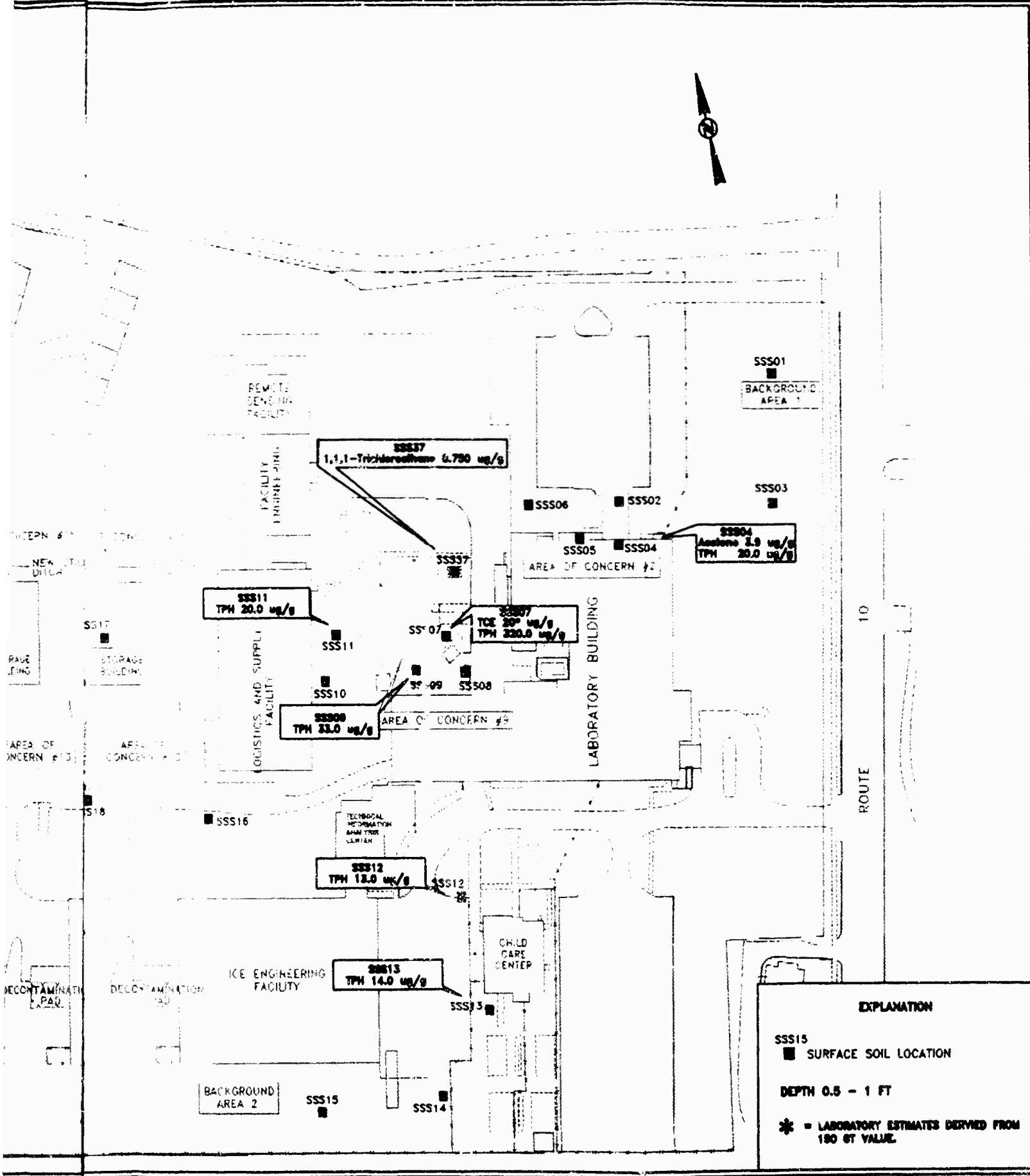
SCIE

4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90 92 94 96 98 100 FEET

REF. NO.
67043-037

卷之五

ANSWER KEY



BY: (INITIALS) DRAWN BY: (INITIALS)
MSB
APPROVED BY: (INITIALS)

Arthur D Little

TITLE:

FIGURE 4-3
COLD REGIONS RESEARCH AND
ENGINEERING LABORATORY
DETECTED COMPOUNDS IN SURFACE SOIL

TABLE 4-6: Detected Compounds In Surface Soil
CRREL Site Investigation

Sample ID	Location	AOC*	ANOL	S68304		S68307		S68311		S68313	
				AOC*	ANOL	AOC*	ANOL	AOC*	ANOL	AOC*	ANOL
68304 D-172 D-173 Collection Date:		0.5	0.5	02-AUG-93	03-AUG-93	02-AUG-93	03-AUG-93	02-AUG-93	03-AUG-93	02-AUG-93	03-AUG-93
VOLATILE ORGANIC COMPOUNDS (µg/g)											
HALOGENATED ORGANICS											
1,1,1-Trichloroethane		-	-	120 ^b	-	-	-	-	-	-	-
Trichloroethane											
TOTAL PETROLEUM HYDROCARBONS (µg/g)				20	320	33	20	13	14	20	18
											-

Notes:

* = Laboratory estimate derived from reported 10GST value

- = Less than detection limit or not detected

Arthur D Little

CRREL: RI Report
Section No.: 4.0
Revision No.: 1
Date: March 18, 1994

The interpretation of the Phase I soil gas survey results revealed that TCE ion flux anomalies correlated well with the AOCs identified prior to the survey. In particular, anomalies were detected at AOCs 2, 9, 13, and 16. A smaller scale of ion counts was detected at AOCs 6 and 15. TCE flux anomalies detected in the Phase II soil gas survey were found in AOCs 16 and 15, with smaller areas of flux west of the lower terrace access road, adjacent to the pond, and southwest of AOC 8. Figure 4-4 illustrates the TCE relative response fluxes detected in the Phase II investigation.

BTEX relative ion flux anomalies were identified at AOCs 2, 6, 10, 13, and 16 during the Phase I survey. BTEX interpretation during the Phase II investigation identified flux anomalies in AOC 10 and west of the lower terrace access road. Moderate-response flux anomalies were also detected near CRREL pond. Figure 4-4 illustrates the BTEX relative response fluxes detected during the Phase II investigation.

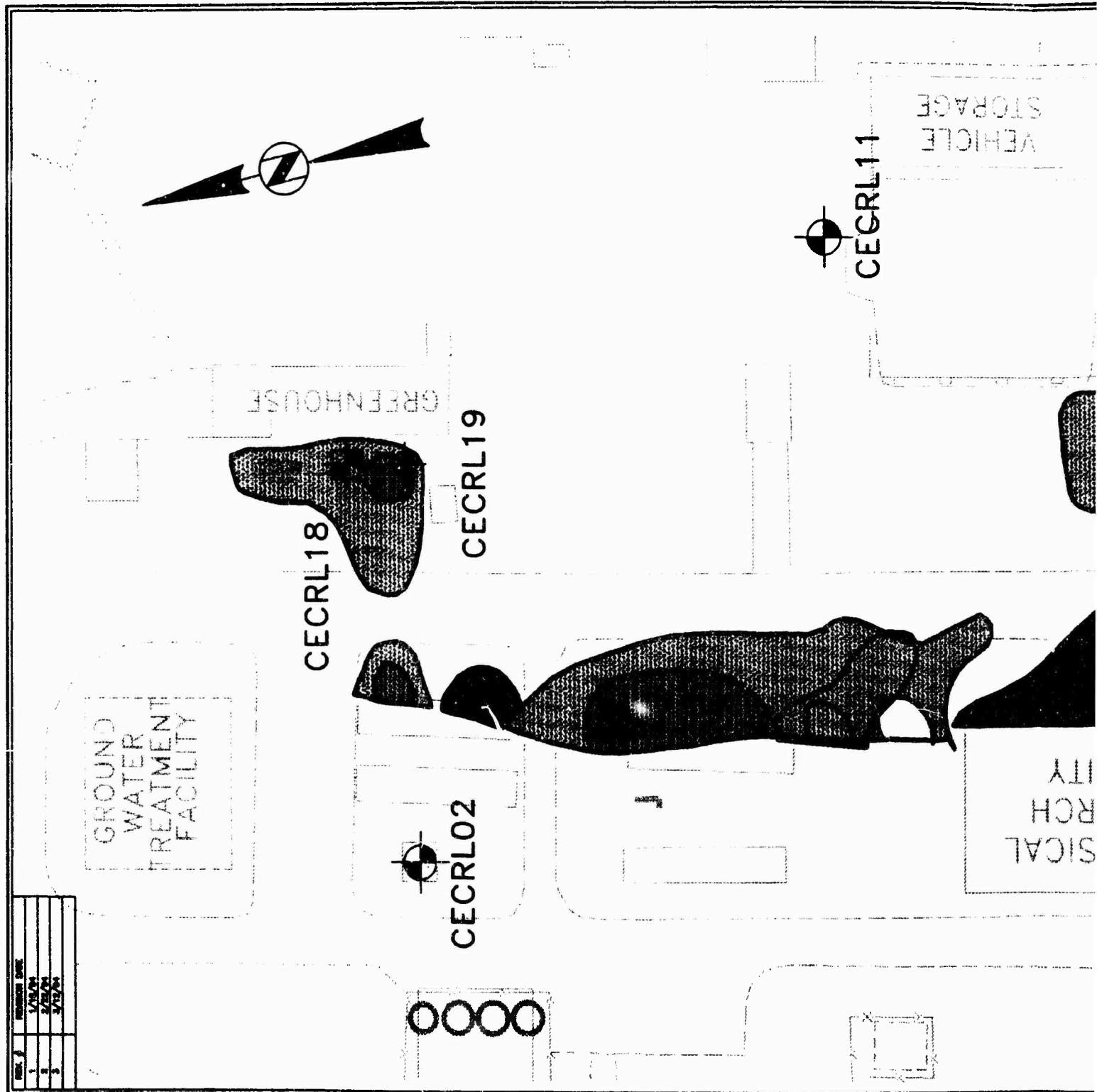
Regarding PCE, both surveys indicated that the highest anomalies were located in AOC 16, with the Phase II survey also revealing comparably high anomalies west of the lower terrace access road south of AOC 16. Moderate-response anomalies were detected at AOC 6 during the Phase I survey and also near CRREL pond during the Phase II investigation.

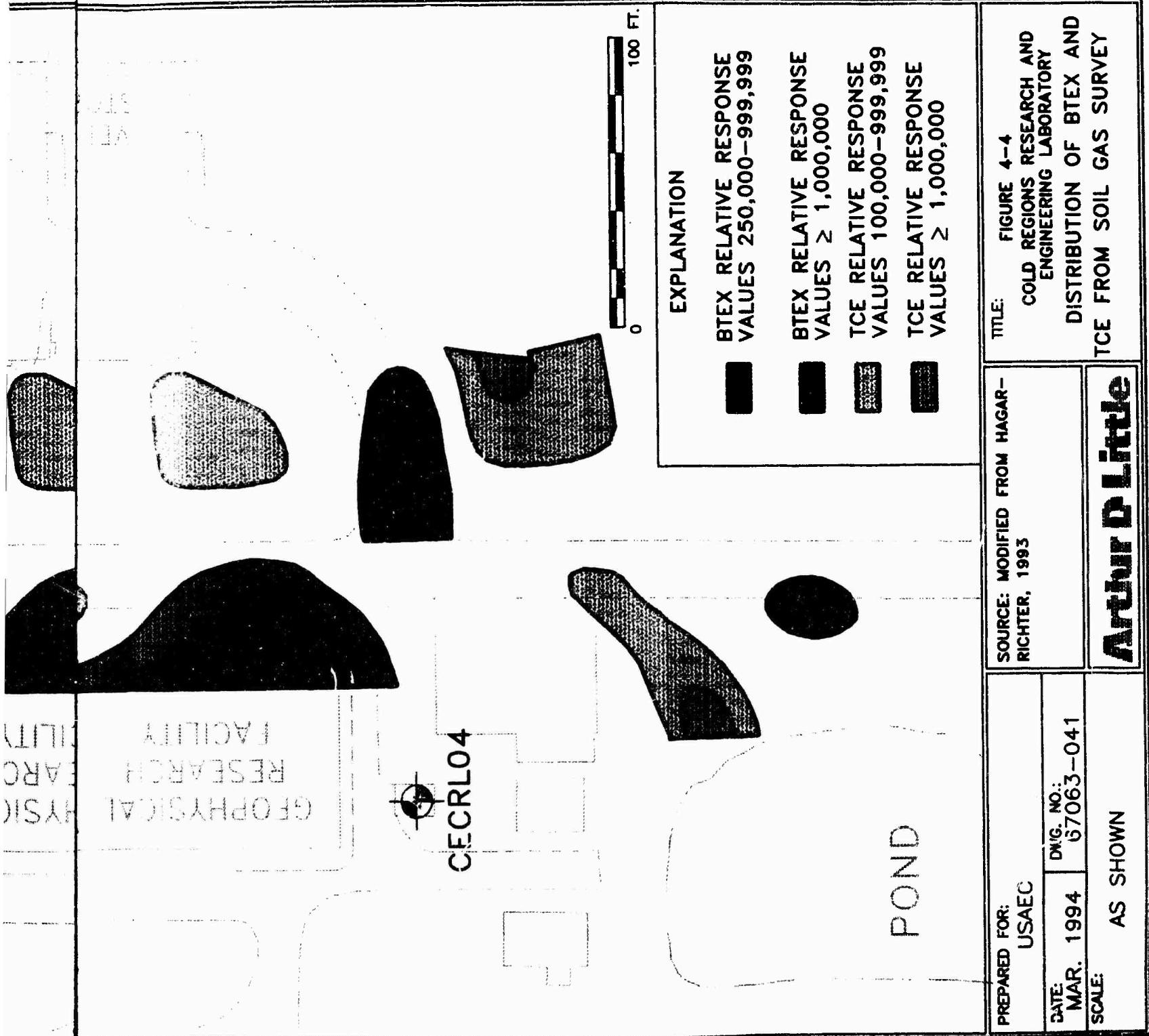
The fuel oil character anomalies were identified at AOCs 2, 6, and 13 in the Phase I survey. Also, DCE was detected at four sample locations near AOC 9, and Freon 11, 1-1-1-trichloroethane, and carbon tetrachloride anomalies were identified at a few sample locations. In the Phase II survey of cycloalkanes and alkenes, flux anomalies of moderate-response were detected in AOC 16 and west of the lower terrace access road. There was a strong correlation between the cycloalkanes/alkenes fluxes and BTEX fluxes detected in the Phase II survey.

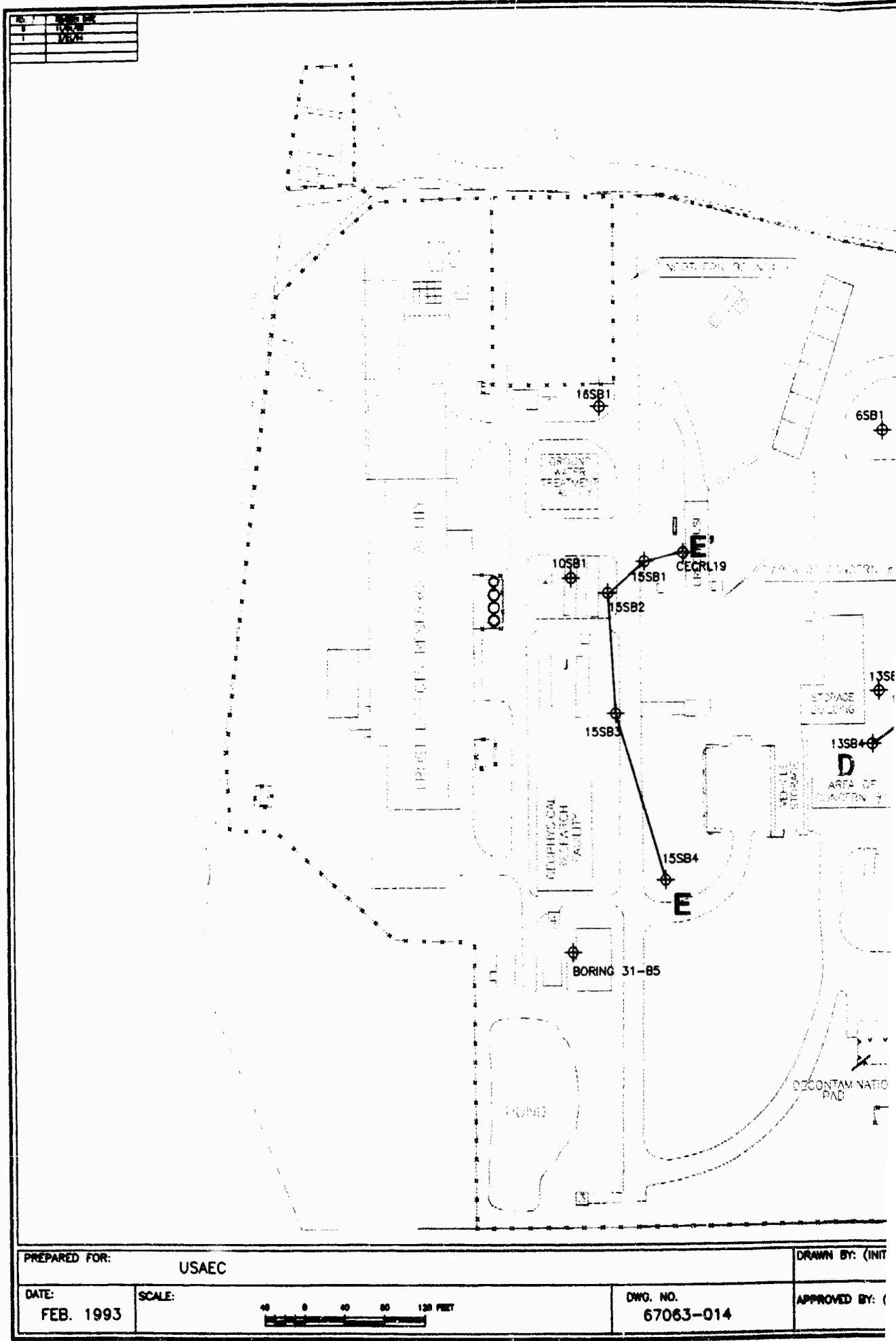
4.4 Subsurface Soil

The nature and extent of subsurface soil contamination is described below for each AOC for which there are data. Figures 4-5 through 4-10 are geologic cross sections based on soil borings that illustrate detected concentrations of contaminants. Table 4-6 summarizes the detected compounds in subsurface soil. Appendix N summarizes all of the analytical results.

At many locations headspace measurements from subsurface soils detected some volatile contamination, while chemical analyses of the same soil were non-detects. This discrepancy may be related to the sampling period over the summer months. VOCs may have volatilized before reaching the laboratory or, due to the nature of the contaminants, filled soil pores but not sorbed to soils.







PREPARED FOR:
USAEC

DRAWN BY: (INIT)

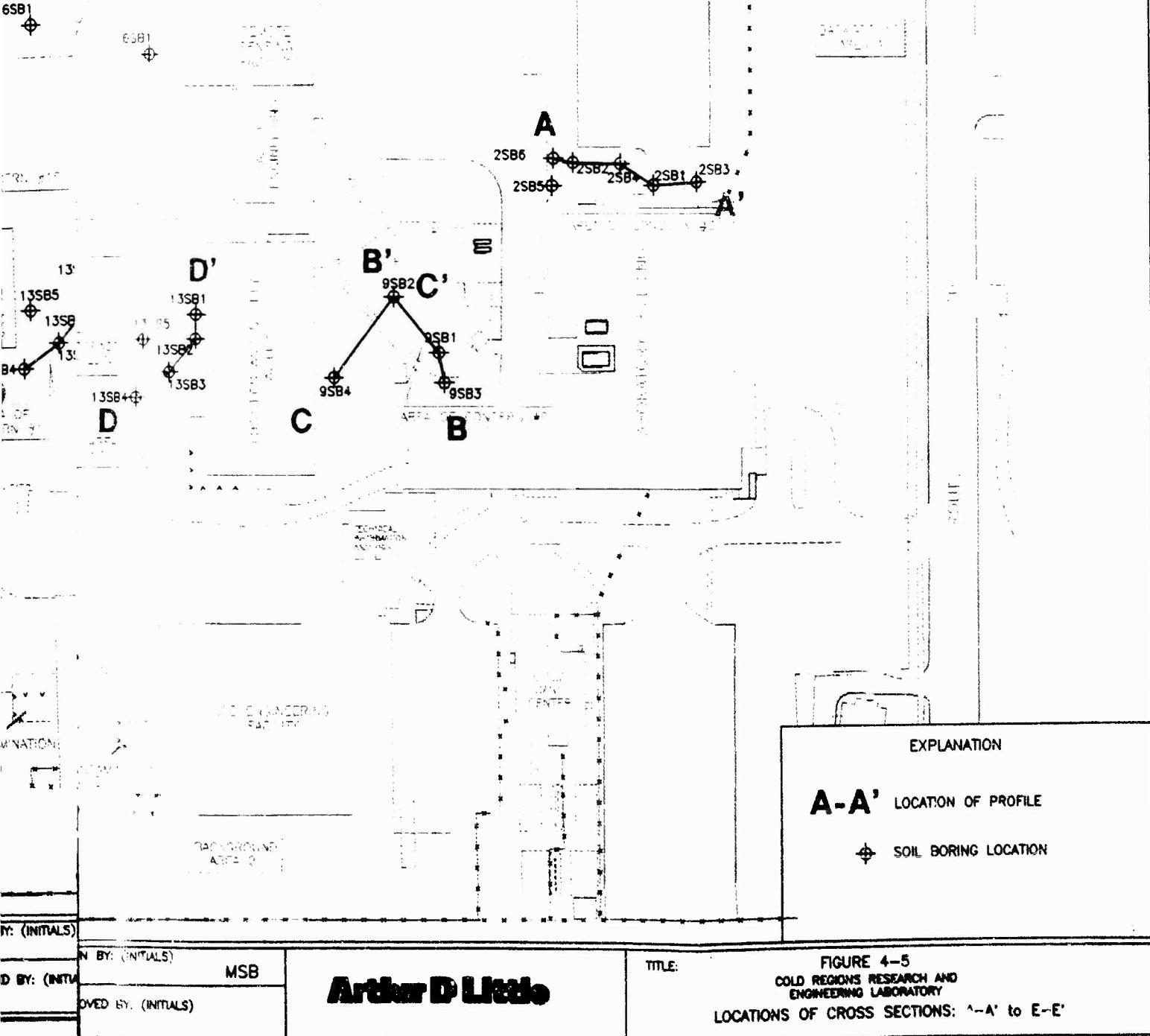
DATE:
FEB. 1993

SCALE:

40 0 40 80 120 FEET

DWG. NO.
67063-014

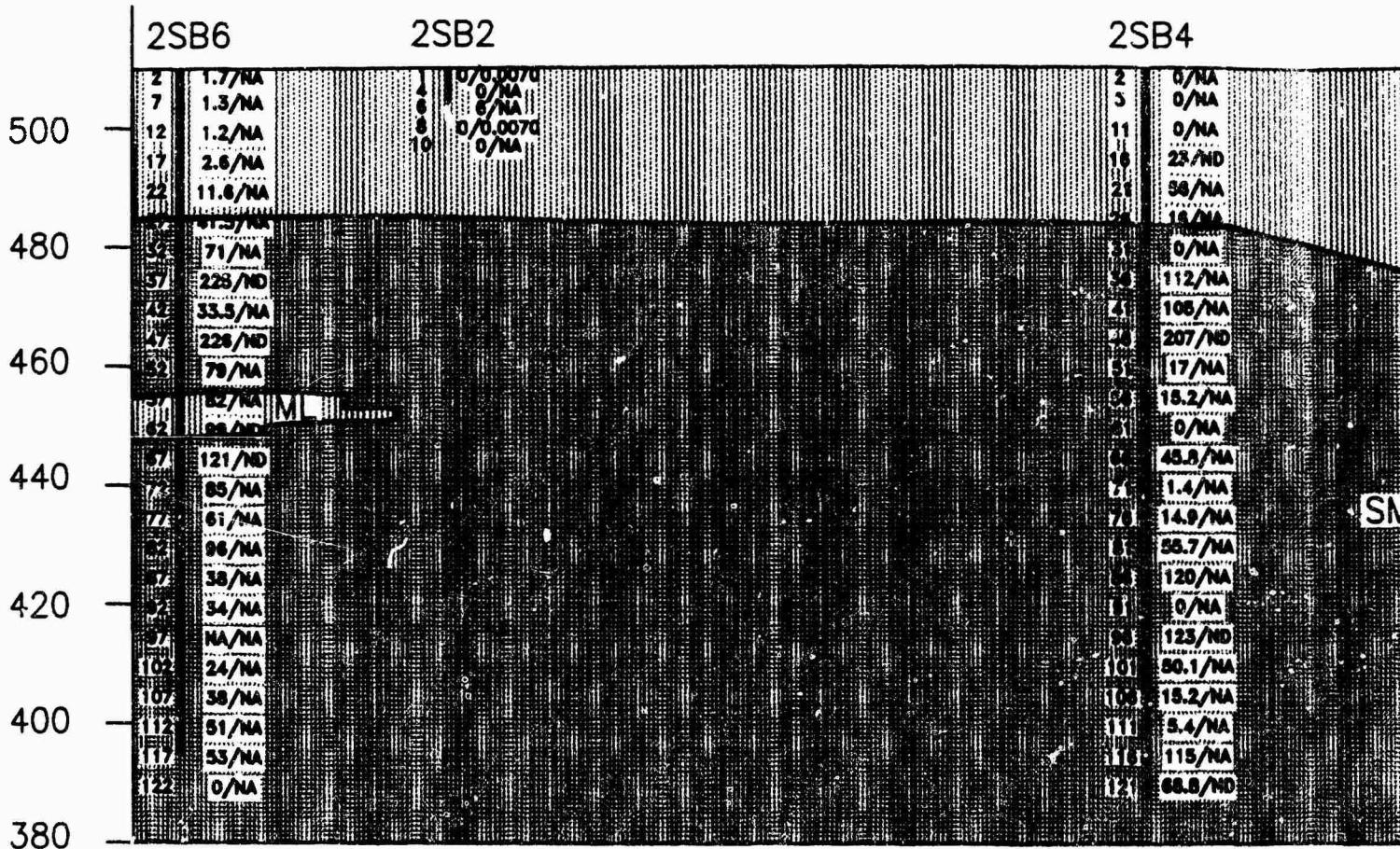
APPROVED BY: (INIT)



REV. #	REVISION DATE
0	1/10/94
1	3/12/94

A

FT(AMSL)



VERTICAL EXAGGERATION = 1X

HORIZONTAL SCALE



2SB4

Depth	PID(HS)/TVOCs
11	0/NA
16	23/ND

HS - HEADSPACE
TVOCs - TOTAL VOCs
ND - NOT DETECTED
NA - NOT ANALYZED

PREPARED FOR:	USAEC	DRAWN BY: (INITIALS)
DATE:	SCALE:	MSB/TG
MAR. 1994	AS SHOWN	DWG. NO. 67063-024 APPROVED BY: (INITIALS)

A'
FT(AMSL)

2SB1

2SB3

ML

4	0/NA
8	5/ND
12	0/ND
16	400/3.0
20	100/NA
24	150/0.010
28	78/NA
32	90/NA
36	88/NA
40	80/NA
44	270/0.022

SM

2	0/NA
7	0/NA
12	0/NA
17	100/NA
22	800/ND
27	2000/ND
32	900/2.8
37	130/ND
42	0/NA
47	0/NA
52	19/NA
57	47/NA
62	0/NA
67	0/NA

500

480

460

440

420

400

380

VOCs

/OCs

TED

ZED

EXPLANATION
ML - INORGANIC SILTS AND VERY
FINE SANDS
SM - SILTY SANDS, SAND-SILT MIXTURES

MSB/TG

Arthur D Little

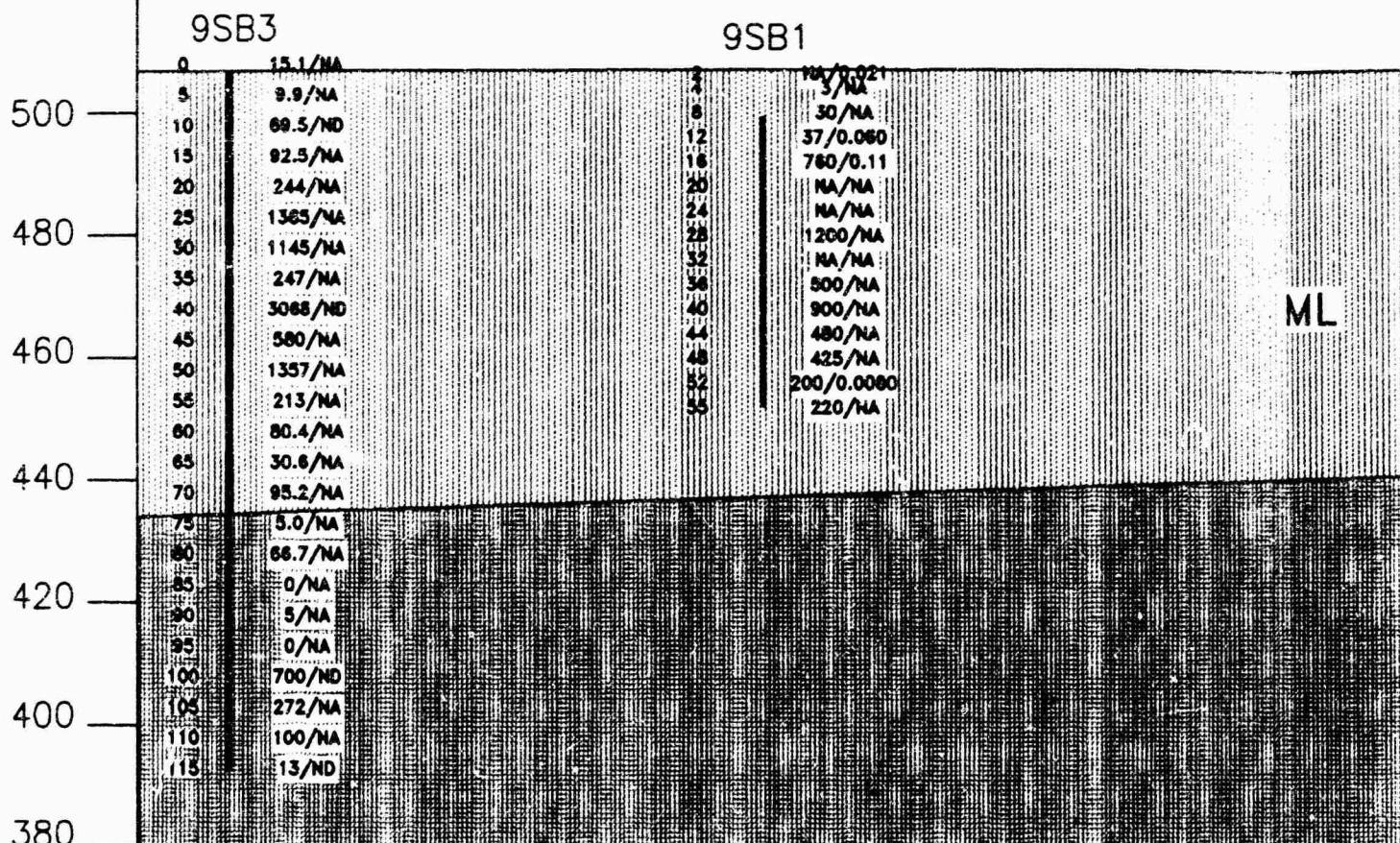
TITLE:

FIGURE 4-6
Cold Regions Research and Engineering
Laboratory
Geologic Cross Section A-A': AOC 2

REV. #	REVISION DATE
0	11/10/93
1	1/10/94
2	3/12/94

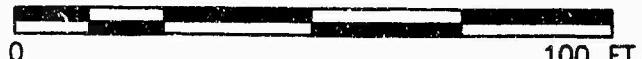
B

FT(AMSL)



VERTICAL EXAGGERATION = 1X

HORIZONTAL SCALE



9SB3

Depth	PID(HS)/TVOCs
10	69.5/ND
15	92.5/NA

HS - HEADSPACE
 TVOCs - TOTAL VOCs
 ND - NOT DETECTED
 NA - NOT ANALYZED

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USAEC

DRAWN BY: (INITIALS)

MSB/TG

DATE:

MAR. 1994

SCALE:

AS SHOWN

DWG. NO.

67063-050

APPROVED BY: (INITIALS)

ML

SM

B'
FT(AMSL)

9SB2

0	0/NA	500
4	0/NA	
9	0/NA	
14	0/NA	
19	0/NA	
24	0/NA	
29	0/NA	
34	0/NA	
39	0/NA	
44	0/NA	
49	49/ND	
54	162.1/ND	
59	52.1/ND	
64	1.5/NA	
69	18.2/ND	440
74	7.2/NA	
79	28/NA	
84	7.2/NA	
89	20.8/ND	
94	0/NA	
99	0/NA	

s HS)/TVOCS
/ND
/NA

SPACE
TAL VOCs
DETECTED
ANALYZED

EXPLANATION

 ML - INORGANIC SILTS AND VERY FINE SANDS

 SM - SILTY SANDS, SAND-SILT MIXTURES

TG (INITIALS) MSB/TG
BY: (INITIALS)

Arthur D Little

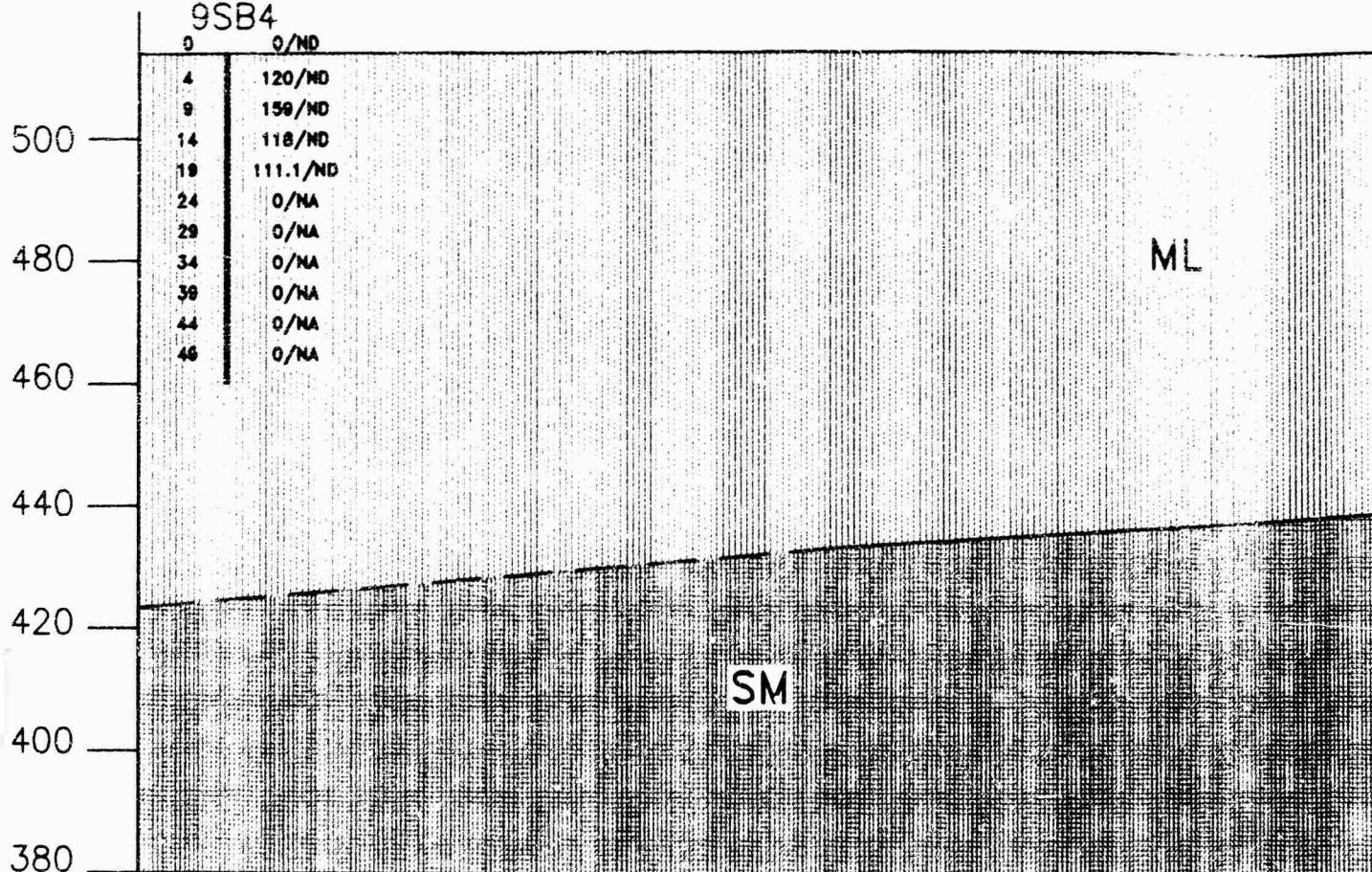
TITLE:

FIGURE 4-7
COLD REGIONS RESEARCH AND ENGINEERING
LABORATORY
GEOLOGIC CROSS SECTION B-B': AOC 9

REV. #	REVISION DATE
0	11/10/93
1	1/10/94
2	3/12/94

C
FT(AMSL)

9SB4



VERTICAL EXAGGERATION = 1X

HORIZONTAL SCALE



9SB4	
Depth	PID(HS)/TVOCs
4	120/ND
9	159/ND

HS - HEADSPACE
 TVOCs - TOTAL VOCs
 ND - NOT DETECTED
 NA - NOT ANALYZED

PREPARED FOR:

USAFC

DRAWN BY: (INITIALS)

MSB/TG

DATE:
MAR 1994

SCALE:

AS SHOWN

DWG. NO.
67063-047

APPROVED BY: (INITIALS)

C'
FT(AMSL)

9SB2

0/NA

4 0/NA

9 0/NA

14 0/NA

19 0/NA

24 0/NA

29 0/NA

34 0/NA

39 0/NA

44 0/NA

49 49/ND

54 182.1/ND

59 52/NA

64 18/NA

69 18.2/ND

74 7.2/NA

79 28/NA

84 7.2/NA

89 20.8/ND

94 0/NA

99 0/NA

500

480

460

440

420

400

380

EXPLANATION



ML - INORGANIC SILTS AND VERY
FINE SANDS



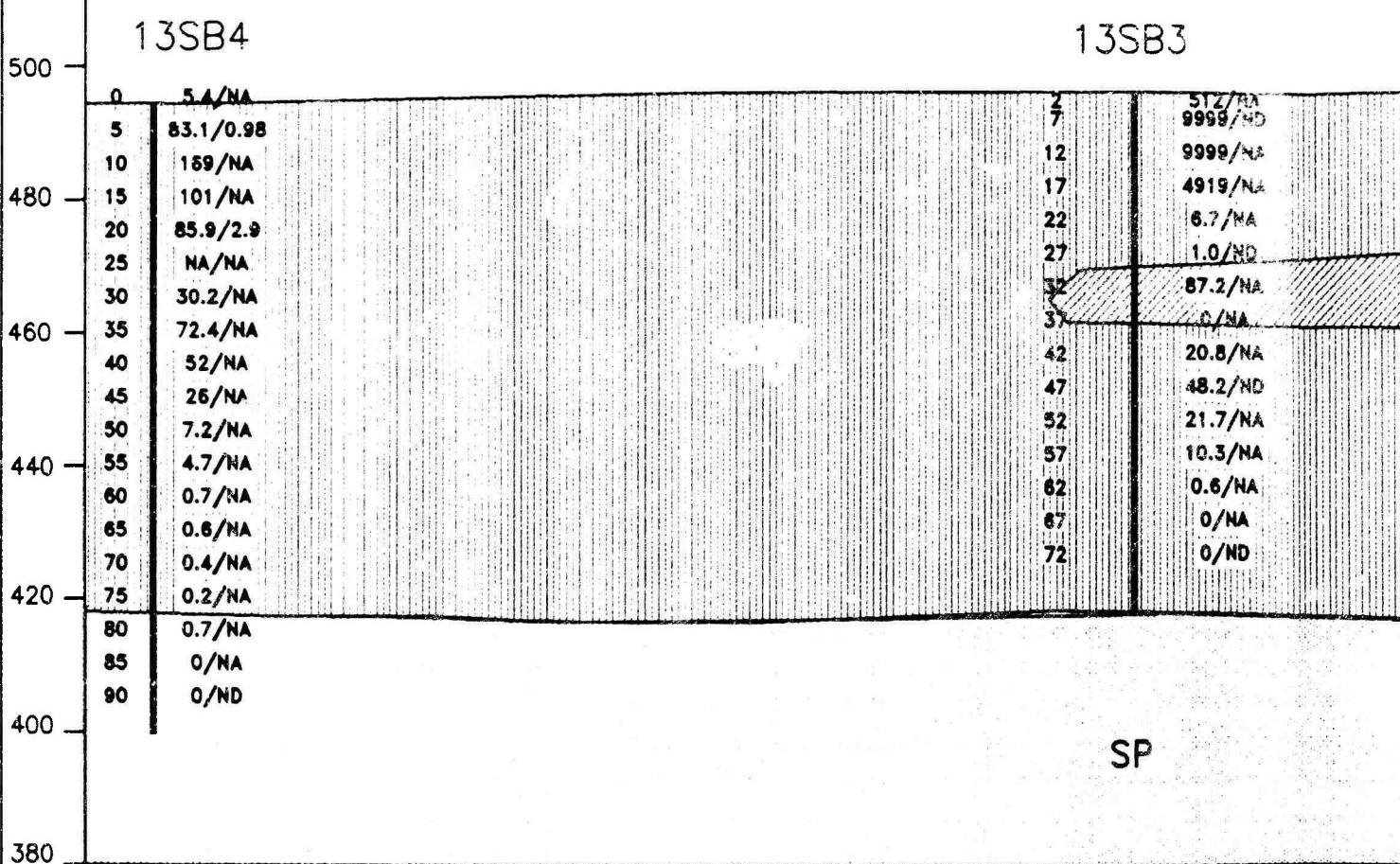
SM - SILTY SANDS, SAND-SILT MIXTURES

TG	MSB/TG	Arthur D Little	TITLE: FIGURE 4-8 COLD REGIONS RESEARCH AND ENGINEERING LABORATORY GEOLOGIC CROSS SECTION C-C': AOC 9
ALS) INITIALS)			

REV. #	REVISION DATE
0	1/7/94
2	3/12/94

D

FT(AMSL)



VERTICAL EXAGGERATION = 1X

HORIZONTAL SCALE



13SB4

Depth	PID(HS)/TVOCs
10	169/NA
15	101/NA

HS - HEADSPACE
 TVOCs - TOTAL VOCs
 ND - NOT DETECTED
 NA - NOT ANALYZED

PREPARED FOR:

USAEC

DRAWN BY: (INITIALS)

DATE:
MAR. 1994

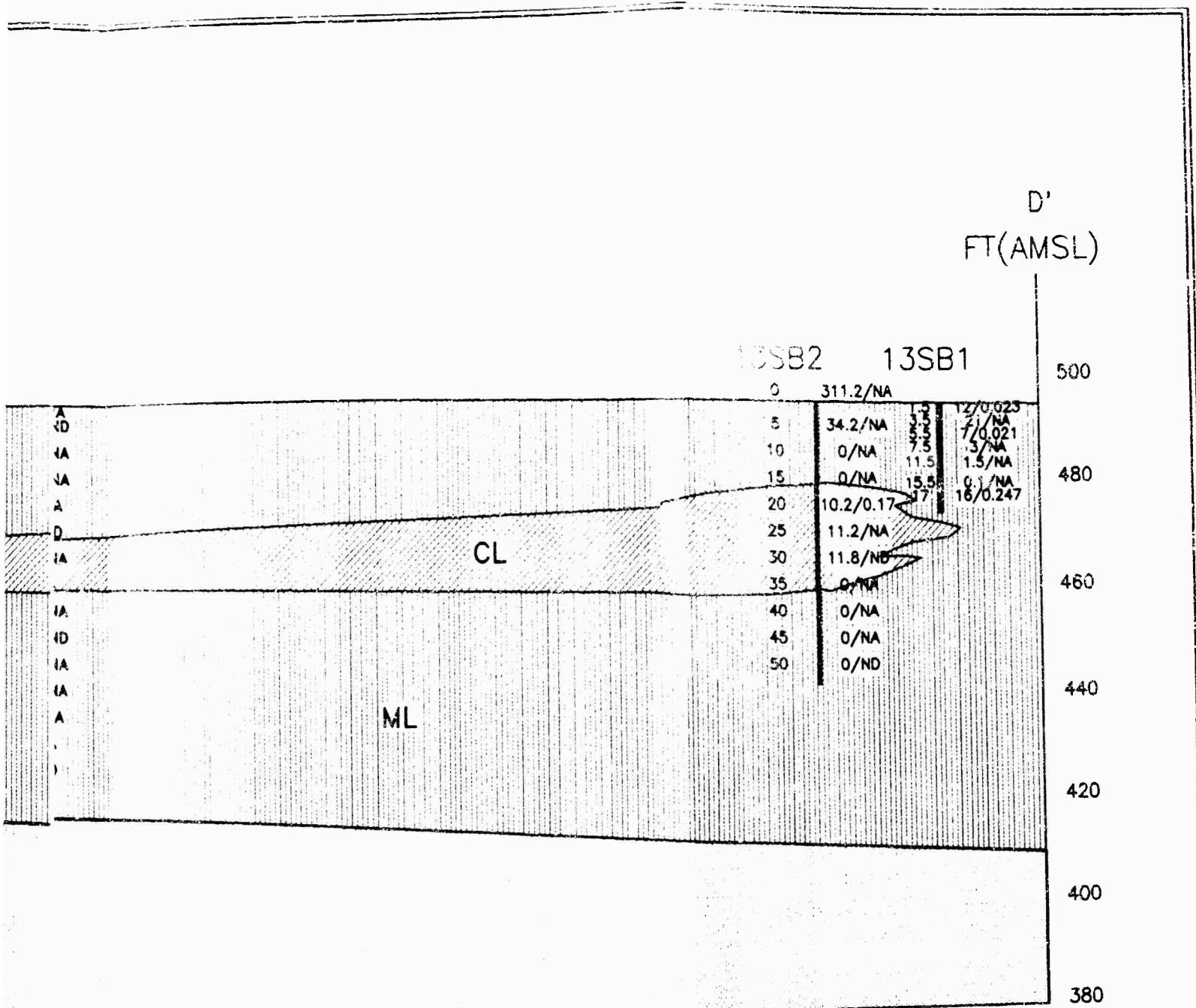
SCALE:

AS SHOWN

Dwg. No.

67063-052

APPROVED BY: (INITIALS)



TVOCs

E
VOCs
CTED
YZED

EXPLANATION

- ML - INORGANIC SILTS AND VERY FINE SANDS
- CL - INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY
- SP - WELL SORTED SANDS

(INITIALS)

(INITIALS)

Arthur D Little

TITLE:

FIGURE 4-9
Cold Regions Research and Engineering
Laboratory
Geologic Cross Section D-D': AOC 13

REV. #	REVISION DATE
0	11/15/93
1	1/11/94
2	3/12/94

E
FT (AMSL)

500

15SB4

460

420

380

340

300

ML

SP/SW

BEDRO

VERTICAL EXAGGERATION = 1X

HORIZONTAL SCALE

0

80 FT.

PREPARED FOR:

USAEC

DRAWN BY: (INITIALS)
MSB

DATE:

MAR. 1994

SCALE:

AS SHOWN

DWG. NO.

67063-051

APPROVED BY: (INITIALS)

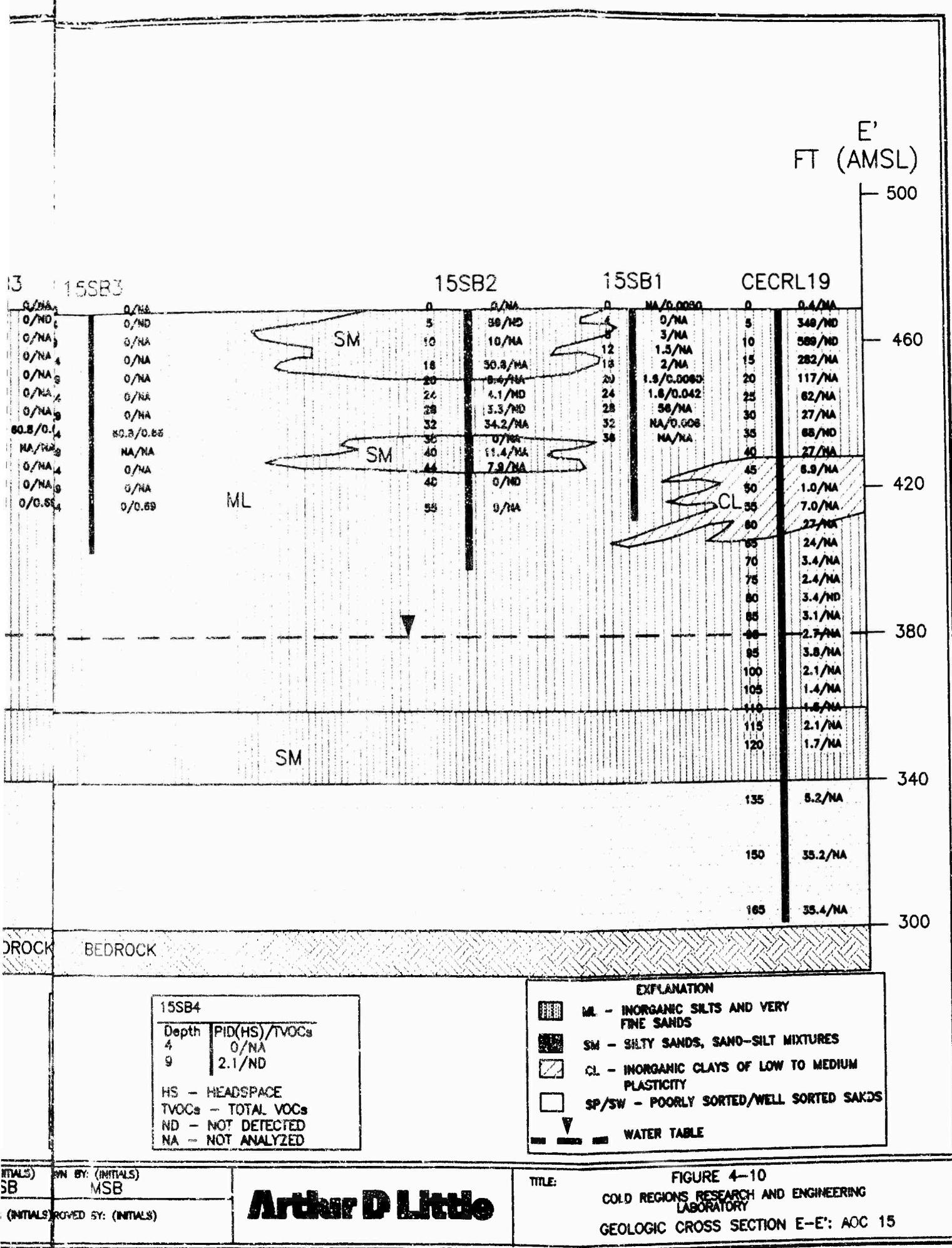


Table 4-6: Detected Compounds in Subsurface Soil
CRRRL Site Investigation

Page 1 of 6

Site ID Site Type Sample Depth (ft) Collection Date Notes	2SB1			2SB1			2SB2			2SB3		
	BORE 15 18-Jun-92	BORE 24 18-Jun-92	SOIL 44 18-Jun-92 Dried	BORE 1 20-Jun-92	BORE 1 20-Jun-92	SOIL 50 21-Jun-92	BORE 0 20-Jun-92	BORE 1 20-Jun-92	SOIL 21 21-Jun-92	BORE 0 21-Jun-92	SOIL 50 21-Jun-92	
VOLATILE ORGANIC COMPOUNDS (ug/g)												
AROMATICS												
Toluene	-	-	-	-	-	-	-	-	-	-	-	
Ethylbenzene	-	-	-	-	-	-	-	-	-	-	-	
m-Xylene	-	-	-	-	-	-	-	-	-	-	-	
o-Xylene	-	-	-	-	-	-	-	-	-	-	-	
HALOGENATED ORGANICS												
Methylene Chloride	0.011	0.010	-	0.0090	0.0060	-	0.0070	-	-	-	-	
1,2-Dichloroethylene	-	-	-	-	-	-	-	-	-	-	-	
cis-1,2-Dichloroethylene	-	-	-	-	-	-	-	-	-	-	-	
trans-1,2-Dichloroethylene	-	-	-	-	-	-	-	-	-	-	-	
Trichloroethane	3 *	-	-	-	-	-	-	-	-	-	-	
WATER SOLUBLES												
Methyl Ethyl Ketone (MEK)/2-Butanone	-	-	-	-	0.014	-	-	-	-	-	-	
TOTAL PETROLEUM HYDROCARBONS (ug/g)												
Notes:												
- indicates less than detection limit or not detected												
* significant figures reflect dilution factor												

Notes:

- indicates less than detection limit or not detected
- * significant figures reflect dilution factor

Table 4-6: Detected Compounds in Subsurface Soil
CRREL Site Investigation

Site ID	6SB1	6SB1 Bore 1	6SB1 Bore 2	6SB1 Bore 3	6SB1 Bore 4	6SB1 Bore 5	6SB1 Bore 6
Site Type Surface Depth (ft) Collection Date 00/1/94	25-Jan-94 30-Jan-94	16-Jan-94 18-Jan-94	16-Jan-94 18-Jan-94	17-Jan-94 18-Jan-94	17-Jan-94 18-Jan-94	16-Jan-94 18-Jan-94	16-Jan-94 18-Jan-94
VOLATILE ORGANIC COMPOUNDS (ug/g)							
AROMATICs							
Toluene	-	-	-	-	-	-	-
Ethylbenzene	-	-	-	-	-	-	-
m-Xylene	-	-	-	-	-	-	-
c-Xylene	-	-	-	-	-	-	-
HALOGENATED ORGANICS							
Methylene Chloride	0.0070	0.0060	0.0040	0.0080	0.0030	0.0080	0.0050
1,2-Dichloroethanes/1,2-Dichloroethenes (cis and trans isomers)	-	-	-	-	-	-	-
cis-1,2-Dichloroethylene/1,2-Dichloroethene	-	-	-	-	-	-	-
Trichloroethene	-	-	0.017	0.051	0.11	-	-
WATER SOLUBLES							
Methylethyl Ketone (MEK)/2-Butanone	-	-	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/g)							
	-	-	-	-	-	-	-

Notes:
 - indicates less than detection limit or not detected
 # significant figures reflect dilution factor

Table 4-6: Detected Compounds In Subsurface Soil
CRREL Site investigation

Site ID	Sample Type	Sample Depth (ft)	Collection Date	GC Type	10SB1 Soil 6 14-Jun-94	10SB1 Soil 8 14-Jun-94	12SB1 Soil 13 soil-leach	12SB1 Soil 14 20-Jun-94	12SB1 Soil 15 Dissolved	13SB1 Soil 17 20-Jun-94	13SB1 Soil 18 Dissolved	
VOLATILE ORGANIC COMPOUNDS (ug/g)												
AROMATICOS												
Toluene												
Ethylbenzene												
m-Xylene												
o-Xylene												
HALOGENATED ORGANICS												
Methylene Chloride												
1,2-Dichloroethylene*												
cis-1,2-Dichloroethylene/cis-1,2-Dichloroethene												
Trichloroethane												
WATER SOLUBLES												
Methylethyl Ketone (MEK)/2-Butanone												
TOTAL PETROLEUM HYDROCARBONS (ug/g)												

Notes:

- * indicates less than detection limit or not detected
- # significant figures reflect dilution factor

07-ALB-94.DOCN1HT.M01

Page 5 of 6

三

— indicates less than detection limit or not detected
* significant figures reflect dilution factor

Table 4-6: Detected Compounds in Subsurface Soil
CRREL Site Investigation

Page 6 of 6

Site ID: Site Type: Surface Depth (ft) Detection Date: CO.1901	CECRL19 NONE 10 26-Jul-88	
VOLATILE ORGANIC COMPOUNDS (ug/g)		
	AROMATICs	
	Toluene	
	Ethylbenzene	
	m-Xylene	
	o-Xylene	
	HALOGENATED ORGANICS	
	Methylene Chloride	
	1,2-Dichloroethylene/1,2-Dichloroethenes (cis and trans isomers)	
	cis-1,2-Dichloroethylene/cis-1,2-Dichloroethene	
	Trichloroethene	
	WATER SOLUBLES	
	Methyl Ketone (MEK)/2-Butanone	
	TOTAL PETROLEUM HYDROCARBONS (ug/g)	
		770

Notes:

- indicates less than detection limit or not detected
- # significant figures reflect dilution factor

CRREL: RI Report
Section No.: 4.0
Revision No.: 1
Date: March 18, 1994

4.4.1 AOC 1: Former TCE Storage Area

No subsurface soil samples were collected from AOC 1.

4.4.2 AOC 2: Former TCE and Fuel Oil UST Area

TCE was detected in silt units from 2SB1 and 2SB3 at depths of 15 to 17 and 30 to 32 feet bgs (Figure 4-6) at concentrations of 3 and 2.9 µg/g, respectively. Both of these borings are located at the eastern side of AOC 2.

Low concentrations of methylethyl ketone were detected in boring 2SB1 (0.014 µg/g) at the 44- to 46-foot interval.

Methylene chloride, a suspected laboratory contaminant, was detected in all AOC 2 samples with the exception of the 30- to 32-foot bgs sample from 2SB3, at concentrations ranging from 0.0070 to 0.011 µg/g.

Field screening data from PID headspace analysis suggest that VOC contamination of the subsurface soil beneath AOC 2 may be present deeper than the last (deepest) soil sample collected at the location. VOC gases may only be present in soil and not necessarily in the ground water. Field screening data indicated that concentrations of total VOCs exceeding 10 ppm were first detected between 14 and 20 feet bgs (Appendix G) and continued to depths of 57 and 117 feet bgs in 2SB3 and 2SB6 respectively. The presence of elevated headspace screening results at the termination of the 2SB4 and 2SB5 borings indicates that VOC contamination extends deeper than the completion depth of 120 feet bgs. Ground water in the vicinity of AOC 2 is approximately 134 feet bgs and thus necessitated the completion depth of 120 feet bgs (Section 2.4.2). Total VOCs were not detected in 2SB2, however, the boring was terminated at 10 feet.

4.4.3 AOC 3: Facility Engineering's Former Fuel Oil UST

No subsurface soil samples were collected from AOC 3.

4.4.4 AOC 4: Facility Engineering's Current Fuel Oil UST

No subsurface soil samples were collected from AOC 4.

4.4.5 AOC 5: Diesel Fuel and Gasoline ASTs

No subsurface soil samples were collected from AOC 5.

4.4.6 AOC 6: Former Gasoline USTs

Based on the one boring drilled (6SB1) to 10 feet bgs, no contamination was detected. Similarly, field screening of headspace showed no indication of VOC contamination. Methylene chloride, a suspected laboratory contaminant, was detected at concentrations of 0.0070 µg/g at 1 to 3 feet bgs and 0.0080 µg/g at 8.5 to 10.5 feet bgs.

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4.4.7 AOC 7: Fuel Oil UST

No subsurface soil samples were collected from AOC 7.

4.4.8 AOC 8: Waste Oil AST

No subsurface soil samples were collected from AOC 8.

4.4.9 AOC 9: Ice Well

TCE was detected in silt units from boring 9SB1 at depths of 2 to 4 (0.017 µg/g), 13 to 15 (0.051 µg/g), and 17 to 19 (0.11 µg/g) feet bgs. Figure 4-7 illustrates the detection intervals.

Methylene chloride, a suspected laboratory contaminant, was detected in all 9SB1 samples at concentrations ranging from 0.0030 to 0.0090 µg/g.

Field screening data from PID headspace analysis suggest that VOC contamination of the subsurface soil beneath AOC 9 may be present deeper than the last (deepest!) soil sample collected at the location (Figure 4-7 and 4-8). VOC gases may only be present in soil and not necessarily in the ground water. The headspace data indicated that concentrations of total VOCs exceeding 10 ppm were detected near the ground surface at the 0 to 2-foot interval in 9SB3 (Appendix G). The vertical extent of VOC contamination was defined by headspace readings in borings 9SB2 and 9SB4 at 94 and 21 feet bgs, respectively. However, the presence of elevated headspace screening results at the termination of the boring indicate that VOC contamination likely extends deeper than the completion depth of 55 and 115 feet bgs at 9SB1 and 9SB3. Ground water in the vicinity of AOC 2 is approximately 129 feet bgs, and thus necessitated the completion depth of 115 bgs in 9SB3 (Section 2.4.2). The completion depth for 9SB1 was determined in accordance with the E&E Work Plan (1991).

4.4.10 AOC 10: Former Open Storage Area

Based on the one boring (10SB1) drilled to 10 feet bgs, no contamination was detected. Similarly, field screening of headspace showed no indication of VOC contamination.

However, methylene chloride, a suspected laboratory contaminant, was detected in all 10SB1 samples with concentrations ranging from 0.0050 to 0.0060 µg/g.

4.4.11 AOC 11: Concrete Storage Pad Area

No subsurface soil samples were collected from AOC 11.

4.4.12 AOC 12: Exterior Test Pond Area

No subsurface soil samples were collected from AOC 12.

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4.4.13 AOC 13 Former Grave Pad

TCE was detected in silt units from 13SB1, 13SB4, and in a clay unit from 13SB5. At 13SB1, TCE was detected at intervals of 1.5 to 3.5 (0.017 µg/g), 5.5 to 7.5 (0.013 µg/g), and 17 to 19 (0.23 µg/g) feet bgs. At 13SB4, TCE was detected at intervals of 5 to 7 (0.98 µg/g) and 20 to 22 (2.3 µg/g) feet bgs. At 13SB5, TCE was detected at the interval of 20 to 22 feet bgs at a concentration of 2.2 µg/g. Figure 4-9 shows the distribution of VOC contamination at AOC 13.

In silt units from 13SB1 and 13SB4, 1,2-dichloroethene isomers (cis and trans) were detected at depths of 5.5 to 7.5 (0.0010 µg/g) and 20 to 22 (0.60 µg/g) feet bgs, respectively.

Cis-1,2-dichloroethene was detected in 13SB1 at concentrations of 0.012 µg/g and 0.0080 µg/g at the respective depths of 5.5 to 7.5 and 17 to 19 feet bgs.

Toluene was detected in 13SB2 at 20 to 22 feet bgs at a concentration of 0.17 µg/g.

Methylene chloride, a suspected laboratory contaminant, was detected in all samples collected from boring 13SB1. These concentrations ranged from 0.0060 to 0.0090 µg/g.

Field screening data from PID headspace analysis suggest that VOC contamination of the subsurface soil beneath AOC 13 may be present deeper than the last (deepest) soil sample collected at the location. VOC gases may only be present in soil and not necessarily in the ground water. The headspace data revealed concentrations of total VOCs exceeding 10 ppm near the ground surface in all boring locations (Appendix G). Measurable VOC contamination from headspace screening continues approximately to 32, 57, and 85 feet bgs in borings 13SB2, 13SB3, and 13SB4, respectively. Extremely high (>4,000 ppm) screening results were encountered between 5 and 15 feet bgs at 13SB3. Headspace readings of 16 ppm were reported from the bottom of 13SB1 (18 feet bgs). Ground water is approximately 113 feet bgs.

4.4.14 AOC 14: Main Laboratory Machine Room

No subsurface soil samples were collected from AOC 14.

4.4.15 AOC 15: Former Greenhouse Fuel Oil UST Area

Low levels of m- and o-xylenes and ethylbenzene were detected at a depth of 25 to 27 feet bgs at 15SB1. This boring was drilled near the former UST. At 15SB3, TCE was detected at the intervals 34 to 36 and 54 to 56 feet bgs with respective concentrations of 0.66 and 0.69 µg/g. TPH were present in borings 15SB1 at a depth of 25 to 27 feet bgs, in 15SB3 at a depth of 34 to 36 feet bgs, in 15SB4 at a depth of 9 to 11 feet bgs, and in CECRL19 at depths of 5 to 7 and 10 to 12 feet bgs. The highest concentrations of TPH were detected closest to the former USTs at CECRL19

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(700 to 770 µg/g), and decreased in concentration away from the former USTs (170 µg/g at 15SB1 and 14 µg/g at 15SB?). Figure 4-10 illustrates the detection intervals.

Methylene chloride, a suspected laboratory contaminant, was detected in all samples from 15SB1 with concentrations ranging from 0.0050 to 0.0060 µg/g.

Headspace screening of total VOCs suggests that lateral migration of contaminants in the soil and perched water zone located in the vicinity of AOC 15 may have occurred. There is no indication of VOC contamination at boring 15SB4, which penetrated dry soil approximately 300 feet south of the former USTs. However, screening detected VOCs in perched water at 34 feet bgs at 15SB3, located approximately 140 feet south of the former UST. Soil from an intermittent perched water zone between 12 and 50 feet bgs at 15SB2 contained elevated concentrations of VOCs as measured by the PID.

4.4.16 AOC 16: Former Open Storage Area

Based on the one boring (16SB1) drilled to 10 feet bgs, no halogenated organic contamination was detected. Similarly, field screening of headspace showed no indication of VOC contamination.

Methylethyl ketone (MEK) was detected at a concentration of 0.014 µg/g in the 7 to 9-foot bgs sample.

Methylene chloride, a suspected laboratory contaminant, was detected at 9 to 11 feet bgs at a concentration of 0.0030 µg/g.

4.5 Ground Water

To assess the nature and extent of ground water contamination, five rounds of samples were collected from ground water monitoring points at CRREL. Round one was preceded by USAEC sampling, during which the production wells (CECRL01 through CECRL05) and the Ice Well (CECRL06) were sampled. The first two rounds of samples were collected from the production wells, the Ice Well, and monitoring wells existing at the time (CECRL07 through CECRL12). The following three rounds of samples were collected from the CRREL production wells, the Ice Well, and all existing monitoring wells from the Phase I and Phase II investigations (CECRL07 through CECRL20). In the fourth round of sampling, CECRL02 was unable to be sampled due to maintenance; CECRL01 could not be sampled during the fifth round of sampling for the same reason. The Hanover standby well was sampled during all five rounds.

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The approved Phase II work plan mandated that two complete rounds of ground water samples be taken, with a 30-day interval between each round. Upon review of the results from the first two rounds of data, and subsequent discussion with USAEC, a third round of ground water samples was collected (see discussion of "GT" values in Section 2.6.3.3.1).

In this section, the ground water monitoring points at CRREL are divided into three categories: the Ice Well, the production wells and the Hanover standby well, and the monitoring wells. Detected compounds from all sampling rounds are discussed accordingly.

Table 4-7 summarizes the detections of chlorinated and non-chlorinated compounds found in the ground water at CRREL. In this table, aromatic hydrocarbons detected by the GC and GC/MS analytical methods are presented. The compounds detected through GC analysis are listed under BTEX Compounds and the compounds detected through GC/MS analysis are listed under Aromatics.

In this section, the results from both analyses are reported. However, the compounds described in Section 4.5.1 were detected using only the GC/MS method and thus no written clarification of method is necessary. In Section 4.5.2 most of the non-chlorinated compounds were detected using the GC method, and therefore, a description of the analytical method used is necessary only when a compound has been detected by both the GC and GC/MS methods, or solely by the GC method. In Appendix O, aromatic hydrocarbons are listed for both the GC and GC/MS analytical methods. Figure 4-11 illustrates the distribution of VOC contamination in ground water for all five rounds of sampling. Figure 4-12 illustrates the distribution of TPH and BTEX contamination in ground water for all five rounds of sampling.

4.5.1 Nature and Extent of Chlorinated Compound Contamination

In the analyses of samples of CRREL ground water, 14 chlorinated compounds were detected:

- TCE
- PCE
- 1,2-Dichloroethene (cis and trans isomers)
- 1,1,2,2-tetrachloroethane
- 1,1-dichloroethene
- Chloroform
- Cis-1,2-dichloroethene
- 1,1-Dichloroethene (1,1-DCA)
- Methylene Chloride

Table 4-7: Detected Compounds in Ground Water
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Site ID	CECRL01 WELL 0	CECRL01 WELL 6	CECRL01 WELL 8	CECRL01 WELL 9	CECRL01 WELL 9
Site Type					
Sample Depth (ft)	10-Aug-91	08-Aug-91	08-Aug-91	08-Aug-91	08-Aug-91
Collection Date					
QC Type					
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	8.4	.00 #	-	-
1,1-Dichloroethane	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethylene/1,2-Dichloroethene(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	-	0.50	-	-	-
Chlordane	-	-	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	800 (900)	500 #	850 #	-	920*
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethane	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylmethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylacetyl ketone (MBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)	-	-	-	-	-

NOTES:

- (-) Indicates analyte detected by Analytical Method UGO 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported

100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Site ID Site Type Sample Depth (ft) Collection Date OC Type	CECRL02 WELL 10-Mar-91	CECRL02 WELL 11-Mar-91	CECRL02 WELL 10-Apr-91	CECRL02 WELL 26-Aug-91	CECRL02 WELL 01-Dec-91
VOLATILE ORGANIC COMPOUNDS (µg/L)					
AROMATICs					
1,2-Dimethylbenzene/n-xylenes	-	-	-	-	-
1,3-Dimethylbenzene/m-xylenes	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
CHLORINATED AROMATICs					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICs					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	3.2	8.3	-	-
1,1-Dichloroethane	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethylene/1,2-Dichloroethene(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	-	0.81	-	-	-
Chloroform	-	3.8	1.4	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	140 (220)	30	7.6	620 *	2,000 #
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	18	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLEs					
Methyl methyl ketone (MEX)/2-Butanone	-	-	-	5,400 **	-
Methylacetyl ketone (MISK)/4-Methyl-2-Pentanone	-	-	-	38	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDs (***)					
1,3-Dimethylbenzene/m-xylenes	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (µg/L)					
NOTES:					
(I) Indicates analytes detected by Analytical Method UGO-5 - Halocarbons in water by GC/CON	** Laboratory estimated value derived from a reported 100 GT detection				
-- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only	*** Detection by Analytical Method AVG - Volatile Aromatic Compounds In water by GC				
* Laboratory estimated value derived from a reported 150 GT detection	# Significant figures reflect dilution factor				

Table 4-7: Detected Compounds In Ground Water
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Site ID	CECR03 WELL	CECR03 WELL	CECR03 WELL	CECR03 WELL	CECR03 WELL
Site Type	0	0	0	0	0
Sample Depth (ft)	10-May-91	08-May-91	10-Apr-91	29-Aug-91	09-Aug-91
Collection Date					
QC Type					
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	7.7	6.2	-	-
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethenes/1,2-Dichloroethane(cs and trans)	-	-	-	-	-
cs-1,2-Dichloroethylene cs-1,2-Dichloroethene	-	-	-	-	-
Chloroform	-	-	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	-	-	-	-	-
1,3-Dichloropropane	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylbutyl ketone (MBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)	-	-	-	-	-

NOTES:

- (+) Indicates analytes detected by Analytical Method UGO 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 G1 detection

** Laboratory estimated value derived from a reported 100 G1 detection

*** Detection by Analytical Method AVB - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Site ID	CECR103 WELL 6	CECR104 WELL 6	CECR104 WELL 6	CECR104 WELL 6	CECR104 WELL 6
Sample Depth (ft)	61-Dec-93	76-Mar-93	59-Mar-93	08-Apr-93	08-Apr-93
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	-	6.8	6.3	-
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethenes/1,2-Dichloroethanes(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethane	-	-	-	-	-
Chlordorm	-	-	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	-	5.3 (4.1)	6.1	3.7	3.1
1,3-Dichloropropane	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)					
NOTES:					
()	Indicates analytes detected by Analytical Method UGO 5 - Halocarbons in water by GC/CON				
--	Dashes indicate that the analyte is present below the detection limit. Table includes detected analytes only				
*	Laboratory estimated value derived from a reported 100 GT detection				
**	Detection by Analytical Method AV8 - Volatile Aromatic Compounds In water by GC				
#	Significant figures reflect dilution factor				

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds In water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds In Ground Water
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Site ID	CECR104	CECR104	CECR105	CECR105	CECR105
Site Type	WELL	WELL	WELL	WELL	WELL
Sample Depth (ft)	•	•	•	•	•
Collection Date	07-Oct-93	01-Dec-93	10-Nov-93	06-Mar-94	10-Apr-94
QC Type					
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	4.1	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	-	-	-	7.5
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethenes/1,2-Dichloroethanes(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	-	-	-	-	-
Chloroform	-	-	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethane	3.1	4.3	100 (55)	50	30
1,3-Dichloropropene	-	-	-	-	-
Dibromo-chloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	--	-	-	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	1.1	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	--	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)	-	-	-	-	-

NOTES:

- (+) Indicates analysis detected by Analytical Method UG05 - Halocarbons in water by GC/CON
- Dashes indicate that the analysis is present below the detection limit; Toluene includes detected analyses only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Site ID	CECR106	CECR108	CECR109	CECR108	CECR109
Site Type	WELL	WELL	WELL	WELL	WELL
Sample Depth (ft)	0	0	0	0	0
Collection Date	25-Aug-93	07-Dec-93	03-Dec-93	18-Nov-93	12-Nov-93
OC Type					
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	200	-
1,3-Dimethylbenzene/m-xylene	-	-	-	100	-
Benzene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	500	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	-	-	-	300 #
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethenes/1,2-Dichloroethene(cis and trans)	-	-	-	100	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	-	-	-	-	-
Chloroform	-	-	-	20	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	6.6	4.6	8.4	30,000 (14,000)	10,000 #
1,3-Dichloropropane	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	-	-	-	200 (2,000) #	1,000 #
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)	-	-	-	-	500,000 #

NOTES:

- (+) Indicates analytes detected by Analytical Method UG0 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit. Table includes detected analytes only.
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds In Ground Water
CRREL Site Investigation

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Site ID	Site Type	CECILIOS		CECILIOS		CECILIOS		CECILIOS	
		WELL	#	WELL	#	WELL	#	WELL	#
	Sample Depth (ft)	10-Apr-02		28-Apr-02		01-May-02		08-May-02	
COLLECTION DATE									
OC TYPE									
VOLATILE ORGANIC COMPOUNDS (ug/L)									
AROMATIC3									
1,2-Dimethylbenzene/o-xylene		-		-		-		-	
1,3-Dimethylbenzene/m-xylene		-		40		480		-	
Benzene		-		7.6		19		-	
Ethylbenzene		-		14		150		-	
Toluene		-		53		180		-	
Trimethylbenzenes		6000	#	-		-		-	
Xylenes (total)		-		47		-		-	
CHLORINATED AROMATICS									
Chlorobenzene		-		-		-		-	
HALOGENATED ORGANICS									
Chloromethane		-		-		-		-	
Chloroethane		-		-		-		-	
Methylene Chloride		2,000	#	-		-		-	
1,1-Dichloroethene		-		6.9		-		-	
1,1-Dichloroethane		-		-		-		-	
1,2-Dichloroethanes/1,2-Dichloroethenes(cis and trans)		-		54		210		-	
cis-1,2-Dichloroethylene cis-1,2-Dichloroethene		-		-		-		-	
Chloroform		-		-		-		-	
1,2-Dichloroethane		-		-		-		-	
1,1,1-Trichloroethane		-		-		-		-	
Carbon Tetrachloride		-		-		-		-	
Bromodichloromethane		-		-		-		-	
Trichloroethene		30,000	#	2,700	*	48,000	*	7,000	#
1,3-Dichloropropane		-		-		-		-	
Dibromochloromethane		-		-		-		-	
1,1,2-Trichloroethane		-		-		-		-	
1,1,2,2-Tetrachloroethane		-		-		370	*	-	
Tetrachloroethene		20,000	#	1,400	*	2700	*	800	#
Carbon Disulfide		-		-		-		-	
WATER SOLUBLES									
Methylethyl ketone (MEK)/2-Butanone		-		-		-		-	
Methylacetyl ketone (MIBK)/4-Methyl-2-Pentanone		-		-		-		-	
Methyl-n-butyl ketone (MBK)/2-Hexanone		-		-		-		-	
OTHER									
Trichlorofluoromethane		-		-		-		-	
BTEX COMPOUNDS (***)									
1,3-Dimethylbenzene/m-xylene		-		-		70	#	31.1	
Ethylbenzene		-		-		20.8		9.22	
Toluene		-		-		100	#	40	
Trimethylbenzenes		-		-		-		-	
Xylenes (Total)		-		-		70	#	36.2	
TOTAL PETROLEUM HYDROCARBONS (ug/L)									
		-		400,000	#	800,000	#	200,000	

NOTES:

- (*) Indicates analytes detected by Analytical Method UGK 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit, Table 1 -- detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds In Ground Water
CRREL Site Investigation

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Site ID	CECRL07 WELL 6 17-Aug-92	CECRL07 WELL 6 24-Aug-92	CECRL07 WELL 6 30-Aug-92	CECRL07 WELL 6 01-Sept-92 (Dilution)	CECRL07 WELL 6 01-Sept-92
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	15	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	6.9	-	-	-	-
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethene/1,2-Dichloroethanes(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	-	-	-	-	-
Chloroform	-	-	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichromethane	-	-	-	-	-
Trichloroethene	89	58	95	22	15
1,3-Dichloropropane	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	13	-	-	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (")					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	8.23	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)					
	-	-	-	-	120

NOTES:

- (+) Indicates analyses detected by Analytical Method UGO 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit. Table includes detected analytes only.
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV3 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds in Ground Water
CRREL Site Investigation

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Site ID	CECRIL08 WELL 10-May-02	CECRIL08 WELL 13-May-02 Dugdown	CECRIL08 WELL 20-Aug-02	CECRIL08 WELL 06-Aug-02 Dugdown	CECRIL08 WELL 06-Aug-02 Dugdown
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	3.0	3.4	200 #	200 #	-
1,1-Dichloroethane	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethanes/1,2-Dichloroethanes(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	-	-	-	-	-
Chlordform	-	-	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	1,000 #	1,000 #	10,000 #	10,000 #	780 #
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	73	52	-	-	-
Methylacetyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trifluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)					
	-	-	-	-	-

NOTES:

- (+) Indicates analyses detected by Analytical Method UGO 5 - Hydrocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analyses only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds In Ground Water
CRREL Site Investigation

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Site ID	CECRL08 WELL 6	CECRL08 WELL 9	CECRL08 WELL 6 Duplicate	CECRL08 WELL 9	CECRL08 WELL 9
SITE TYPE	26-Aug-93	26-Sep-93			
SAMPLE DEPTH (ft)					
COLLECTION DATE					
OC TYPE			Duplicate		
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	6.8	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	1.9	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	1.2	-	-	-
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethylene/1,2-Dichloroethanes(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethane	-	-	-	-	-
Chlordane	-	3.5	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	1.7	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	2,800	410	8,000 #	6,000 #	80,000 #
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylmethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylacetyl ketone (MBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	26	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	4.50	4.13	2.19	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)					
	-	-	140	-	-

NOTES:

- (+) Indicates analytes detected by Analytical Method UGO 5 - Halocarbons in water by GC/CDN
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds in Ground Water
CRREL Site Investigation

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Site ID	CECRL05 WELL	CECRL06 WELL	CECRL07 WELL	CECRL08 WELL	CECRL10 WELL
	28-Apr-92	28-Apr-92	28-Apr-92	28-Apr-92	28-Apr-92
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	6.1	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	9,000 #	-	-	-	35
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethylene/1,2-Dichloroethene(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	-	-	-	-	-
Chloroform	-	-	19	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1 Trichloroethane	-	-	7.6	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethane	200,000 #	100	2000	90,000 #	170
1,3-Dichloropropane	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	9.3	-	-
Tetrachloroethane	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLE					
Methylethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	17	-	-
OTHER					
Trifluorofluoromethane	-	-	33	-	-
BTEX COMPOUNDS (**)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	3.57	3.91	4.83	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)					
	-	300	220	230	-

NOTES:

- (+) Indicates analytes detected by Anal. Ical Method UGQ 5 - Halocarbons in water by GC/CON
- (-) Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- (*) Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds in Ground Water
CRREL Site Investigation

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Site ID	CECWL19 WELL	CECWL30 WELL	CECWL19 WELL	CECWL19 WELL	CECWL11 WELL
Site Type	•	•	•	•	•
Sample Depth (ft)	30 Aug-93	30 Aug-93	08 Sep-93	30 Aug-93	10 Sep-93
QC Type					
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	12
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	6.1	-	-	-	3.9
1,1-Dichloroethane	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethanes/1,2-Dichloroethenes(cis and trans)	-	-	-	-	1.6
cis-1,2-Dichloroethanes/ cis-1,2-Dichloroethene	-	-	-	-	0.5
Chlordane	-	-	-	-	1.7
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	300 *	60	83	110	2,000 *
1,3-Dichloropropene	-	-	-	-	-
Dibromo-chloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	18	-	-
Tetrachloroethene	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylmethyl ketone (MEK)/2-Butanone	-	-	44	-	10
Methylacetyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MBNK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (**)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	12.1	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)	-	-	120	-	-

NOTES:

- Indicates analytes detected by Analytical Method UGO 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7. Detected Compounds in Ground Water
CRREL Site Investigation

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Site ID	COREL11 WELL	COREL11 WELL	COREL11 WELL	COREL11 WELL	COREL11 WELL
	20-Aug-93	20-Aug-93	20-Aug-93 Dilution	20-Aug-93	20-Aug-93
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	-	57	32	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	40 *	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylchloroethane	200 *	-	-	-	-
1,1-Dichloroethene	30 *	-	25	-	-
1,1-Dichloroethane	10 *	-	-	-	-
1,2-Dichloroethylene/1,2-Dichloroethene (cis and trans)	20 *	-	7.9	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethane	-	-	-	-	-
Chlordane	20 *	-	2.8	2.3	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	1.5	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethane	4,000 *	5,200 *	3,700 *	2,700 *	3,000 *
1,3-Dichloropropane	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	40 *	-	-	0.93	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trifluoromethane	-	-	-	-	-
BTEX COMPOUNDS (")					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethybenzene	-	-	-	-	4.23
Toluene	-	-	3.17	2.06	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)					
NOTES:	-	-	-	-	140

- () Indicates analytes detected by Analytical Method UGO 5 - Halogenated in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Site ID	CESCR12 WELL •	CESCR12 WELL S	CESCR12 WELL EV-Avg-14 Dilution	CESCR12 WELL EV-Avg-14	CESCR12 WELL EV-Avg-14
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	2.1
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	32	7.0	62	-	-
1,1-Dichloroethane	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethylene/1,2-Dichloroethene(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	33	5.0	50	-	-
Chloroform	-	-	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethane	190	200 *	300 *	13	23
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethane	0.32	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	36	12	11	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	2.58
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)	-	-	-	170	-

NOTES:

- Indicates analytes detected by Analytical Method UG0 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds In water by GC

* Significant figures reflect dilution factor

Table 4-7: Detected Compounds in Ground Water
CARL Site Investigation

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Site ID	COCWEL12	COCWEL13	COCWEL13	COCWEL13	COCWEL14
Site Type	WELL	WELL	WELL	WELL	WELL
Sample Depth (ft)	6	8	6	8	6
Collection Date	01-Dec-93	01-Aug-93	01-Dec-93	01-Dec-93	01-Aug-93
GC Type					
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	-	19	33	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					2.4
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	-	2.6	-	-
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethene/1,2-Dichloroethanes(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethene/ cis-1,2-Dichloroethane	-	-	-	-	-
Chloroform	-	-	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	400 #	4.9	4.3	3.2	18
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethane	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylisobutyl ketone (MBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	2.97	6.45	39.3	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)	-	-	-	629	-

NOTES:

- (#) Indicates analysis detected by Analytical Method UGO 5 - Halocarbons In water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analyses only.
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method A1/B - Volatile Aromatic Compounds In water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds in Ground Water
CRREL Site Investigation

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Site ID	CERCLIS	CERCLIS	CERCLIS	CERCLIS	CERCLIS
Site Type	WELL	WELL	WELL	WELL	WELL
Sample Depth (ft)	6	8	6	8	8
Collection Date	02-Aug-93	04-Aug-93	04-Aug-93	04-Aug-93	04-Aug-93
GC Type	Diphenid	Diphenid	Diphenid	Diphenid	Diphenid
VOLATILE ORGANIC COMPOUNDS (µg/L)					
AROMATICS					
1,2-Dimethylbenzeno-xyrene	-	-	-	-	-
1,3-Dimethylbenzeno-m-xyrene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	3.6	10 *	10 *	8.2	9.1
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	-	-	-	-
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethylene/1,2-Dichloroethane(cis and trans)	120	100 *	100 *	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethane	-	-	-	-	-
Chlordane	1.9	-	-	-	3.7
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	160	20 *	20 *	41	170 *
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzeno-m-xyrene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	1.79	9.90	11.4	9.04	9.78
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (µg/L)	110	110	110	800	410

NOTES:

- 0 Indicates analytes detected by Analytical Method UG0 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds in Ground Water
CIREL Site Investigation

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Site ID	CECR15	CECR16	CECR16	CECR16	CECR16
Site Type	WELL	WELL	WELL	WELL	WELL
Sample Depth (ft)	0	0	0	0	0
Collection Date	20-Aug-03	22-Aug-03	27-Aug-03	29-Aug-03	29-Aug-03
OC Type	Duplicate	Duplicate	Duplicate	Duplicate	Duplicate
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	-	-	-	-	12
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	-	-	-	-
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethylenes/1,2-Dichloroethenes(cis and trans)	-	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	-	-	-	-	-
Chlordform	-	3.0	2.7	9.5	9.5
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	200 #	3.7	3.5	170	150
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethane	-	-	-	-	-
Carbon Dioxide	-	-	-	-	-
WATER SOLUBLES					
MethylEethyl ketone (MEK)/2-Butanone	-	-	-	-	-
MethylIsobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	4.78	-	-	14.8	22.3
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)	980	280	520	2,000	1,800

NOTES:

- () Indicates analysis detected by Analytical Method UGO 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analyses only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds in Ground Water
CRREL Site Investigation

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Site ID	CCEHL16 WELL 6	CCEHL17 WELL 6	CCEHL17 WELL 6	CCEPL17 WELL 6	CCEPL18 WELL 6
Site Type	01-Aug-93	07-Aug-93	07-Aug-93	08-Aug-93	07-Aug-93
Sample Depth (ft)					
Collection Date					
QC Type					
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	12	-	1.1	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
C-ALKYLATED AROMATICS					
Cl-Substituted benzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	-	-	-	-
1,1-Dichloromethane	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethylene/1,2-Dichlorobenes(cis and trans)	-	-	-	-	-
cis-1,2-Dichloromethane cis-1,2-Dichloroethene	-	-	-	-	-
Chloroform	15	-	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	51	13	34	21	-
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylmethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethylbenzene	-	-	-	-	-
Toluene	7.86	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)	100	-	-	-	-

NOTES:

- (+) Indicates analytes detected by Analytical Method UCC 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds in Ground Water
CRREL Site Investigation

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Site ID	CECRL15 WELL	CECRL16 WELL	CECRL18 WELL	CECRL19 WELL	CECRL19 WELL
Site Type	0	0	0	0	0
Sample Depth (ft)	27-Aug-03	20-Sep-03	02-Dec-03	27-Aug-03	31-Oct-03
Collection Date					
QC Type					
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	2.5	4.4	-	7.3
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	-	-	-	-	-
1,1-Dichloromethane	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethylenes/1,2-Dichloroethenes(cis and trans)	-	-	-	-	-
cis 1,2-Dichloroethene/ cis-1,2-Dichloroethene	-	-	-	-	-
Chloroform	-	-	-	30 *	82
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethane	1.0	110	55	400 *	190
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethane	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylpropyl ketone (MPK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl- <i>n</i> -butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	-	-	-	-	-
BTEX COMPOUNDS (")					
1,3-Dimethylbenzene/xylenes	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	3.06	2.99	-	10.5
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)	-	-	170	-	-

NOTES:

- 0 Indicates analytes detected by Analytical Method UGO 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Table 4-7: Detected Compounds in Ground Water
CRREL Site Investigation

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Site ID	CECRL19 WELL 4 02-Dec-93	CECRL20 WELL 5 26-Aug-93	CECRL20 WELL 0 25-Aug-93 Duplicate	CECRL20 WELL 6 20-Dec-93	CECRL20 WELL 0 09-Dec-93
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICS					
1,2-Dimethylbenzene/o-xylene	--	--	--	--	--
1,3-Dimethylbenzene/m-xylene	--	--	--	--	--
Benzene	--	--	--	--	--
Ethybenzene	--	--	--	--	--
Toluene	--	--	4.7	4.8	1.3
Trimethylbenzenes	--	--	--	--	--
Xylenes (total)	--	--	--	--	--
CHLORINATED AROMATICS					
Chlorobenzene	--	--	--	--	--
HALOGENATED ORGANICS					
Chloromethane	--	--	--	--	--
Chloroethane	--	--	--	--	--
Methylene Chloride	--	--	--	--	--
1,1-Dichloroethene	--	--	--	--	--
1,1-Dichloroethane	--	--	--	--	--
1,2-Dichloroethylenes/1,2-Dichloroethenes(cis and trans)	--	--	--	--	--
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	--	--	--	--	--
Chloroform	90 #	--	--	1.5	--
1,2-Dichloroethane	--	--	--	--	--
1,1,1-Trichloroethane	--	--	--	--	--
Carbon Tetrachloride	--	--	--	--	--
Bromodichloromethane	--	--	--	--	--
Trichloroethene	100 #	19	26	26	36
1,3-Dichloropropane	--	--	--	--	--
Dibromochloromethane	--	--	--	--	--
1,1,2-Trichloroethane	--	--	--	--	--
1,1,2,2-Tetrachloroethane	--	--	--	--	--
Tetrachloroethene	--	--	--	--	--
Carbon Disulfide	10	--	--	--	--
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	--	--	--	--	--
MethylIsobutyl ketone (MIBK)/4-Methyl-2-Pentanone	--	--	--	--	--
Methyl-n-butyl ketone (MNBK)/2-Hexanone	--	--	--	--	--
OTHER					
Trichlorofluoromethane	--	--	--	--	--
BTEX COMPOUNDS (**)					
1,3-Dimethylbenzene/m-xylene	--	--	--	--	--
Ethybenzene	--	--	--	--	--
Toluene	1.77	--	3.68	7.20	--
Trimethylbenzenes	--	--	--	--	--
Xylenes (Total)	--	--	--	--	--
TOTAL PETROLEUM HYDROCARBONS (ug/L)					
	--	2,703	130	--	--

NOTES:

- (+) Indicates analysis detected by Analytical Method UGO 5 - Halocarbons in water by GC/CON
- Dashes indicate that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AVB - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor

Site ID	HANOVER WELL	HANOVER WELL	HANOVER WELL	HANOVER WELL	HANOVER WELL
	08-Aug-02	09-Aug-02	07-Aug-02	20-Aug-02	01-Sep-02
VOLATILE ORGANIC COMPOUNDS (ug/L)					
AROMATICs					
1,2-Dimethylbenzene/o-xylene	-	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Benzene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (total)	-	-	-	-	-
CHLORINATED AROMATICS					
Chlorobenzene	-	-	-	-	-
HALOGENATED ORGANICS					
Chloromethane	-	-	-	-	-
Chloroethane	-	-	-	-	-
Methylene Chloride	6.4	6.7	-	-	-
1,1-Dichloroethene	-	-	-	-	-
1,1-Dichloroethane	-	-	-	-	-
1,2-Dichloroethenes/1,2-Dichloroethanes(cis and trans)	-	-	-	-	-
ca-1,2-Dichloroethylene/ ca-1,2-Dichloroethene	-	-	-	-	-
Chloroform	-	-	-	-	-
1,2-Dichloroethane	-	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-	-
Carbon Tetrachloride	-	-	-	-	-
Bromodichloromethane	-	-	-	-	-
Trichloroethene	-	-	-	-	1.4
1,3-Dichloropropene	-	-	-	-	-
Dibromochloromethane	-	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-	-
Tetrachloroethene	-	-	-	-	-
Carbon Disulfide	-	-	-	-	-
WATER SOLUBLES					
Methylethyl ketone (MEK)/2-Butanone	-	-	-	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-	-
Methyl-n-butyl ketone (MNBK)/2-Hexanone	-	-	-	-	-
OTHER					
Trichlorofluoromethane	--	--	--	--	--
BTEX COMPOUNDS (***)					
1,3-Dimethylbenzene/m-xylene	-	-	-	-	-
Ethybenzene	-	-	-	-	-
Toluene	-	-	-	-	-
Trimethylbenzenes	-	-	-	-	-
Xylenes (Total)	-	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)					
NOTES:					
(*) Indicate analyses detected by Analytical Method UGO-5 - Hydrocarbons in water by GC/CON	** Laboratory estimated value derived from a reported 100 GT detection				
-- Dashes indicate that the analyte is present below the detection limit; Table includes detected analyses only	*** Detection by Analytical Method AV8 - Volatile Aromatic Compounds in water by GC				
* Laboratory estimated value derived from a reported 150 GT detection	# Significant figures reflect dilution factor				

Table 4-7: Detected Compounds In Ground Water
CRIEL Site Investigation

Page 22 of 22

Site ID Site Type Sample Depth (ft) Collection Date GC Type	GOODRICH		PEACOCK	
	WELL C 10-Mar-91	WELL D 19-Mar-91	WELL D 19-Mar-91	WELL D 19-Mar-91
VOLATILE ORGANIC COMPOUNDS (ug/L)				
AROMATICS				
1,2-Dimethylbenzene/o-xylene	-	-	-	-
1,3-Dimethylbenzene/m-xylene	-	-	-	-
Benzene	-	-	-	-
Ethybenzene	-	-	-	-
Toluene	-	-	-	-
Trimethylbenzenes	-	-	-	-
Xylenes (Total)	-	-	-	-
CHLORINATED AROMATICS				
Chlorobenzene	-	-	-	-
HALOGENATED ORGANICS				
Chloromethane	-	-	-	-
Chloroethane	-	-	-	-
Methylene Chloride	-	-	-	-
1,1-Dichloroethane	-	-	-	-
1,1-Dichloroethane	-	-	-	-
1,2-Dichloroethenes/1,2-Dichloroethenes(cis and trans)	-	-	-	-
cis-1,2-Dichloroethylene/ cis-1,2-Dichloroethene	-	-	-	-
Chloroform	-	-	-	-
1,2-Dichloroethane	-	-	-	-
1,1,1-Trichloroethane	-	-	-	-
Carbon Tetrachloride	-	-	-	-
Bromodichloromethane	-	-	-	-
Trichloroethane	17	24	-	-
1,3-Dichloropropane	-	-	-	-
Dibromochloromethane	-	-	-	-
1,1,2-Trichloroethane	-	-	-	-
1,1,2,2-Tetrachloroethane	-	-	-	-
Tetrachloroethane	-	-	-	-
Carbon Disulfide	-	-	-	-
WATER SOLUBLES				
Methylethyl ketone (MEK)/2-Butanone	-	-	-	-
Methylisobutyl ketone (MIBK)/4-Methyl-2-Pentanone	-	-	-	-
Methyl-n-butyl ketone (MBNK)/2-Hexanone	-	-	-	-
OTHER				
Trichlorofluoromethane	-	-	--	--
BTEX COMPOUNDS (***)				
1,3-Dimethylbenzene/m-xylene	-	-	-	-
Ethybenzene	-	-	-	-
Toluene	-	-	-	-
Trimethylbenzenes	-	-	-	-
Xylenes (Total)	-	-	-	-
TOTAL PETROLEUM HYDROCARBONS (ug/L)				

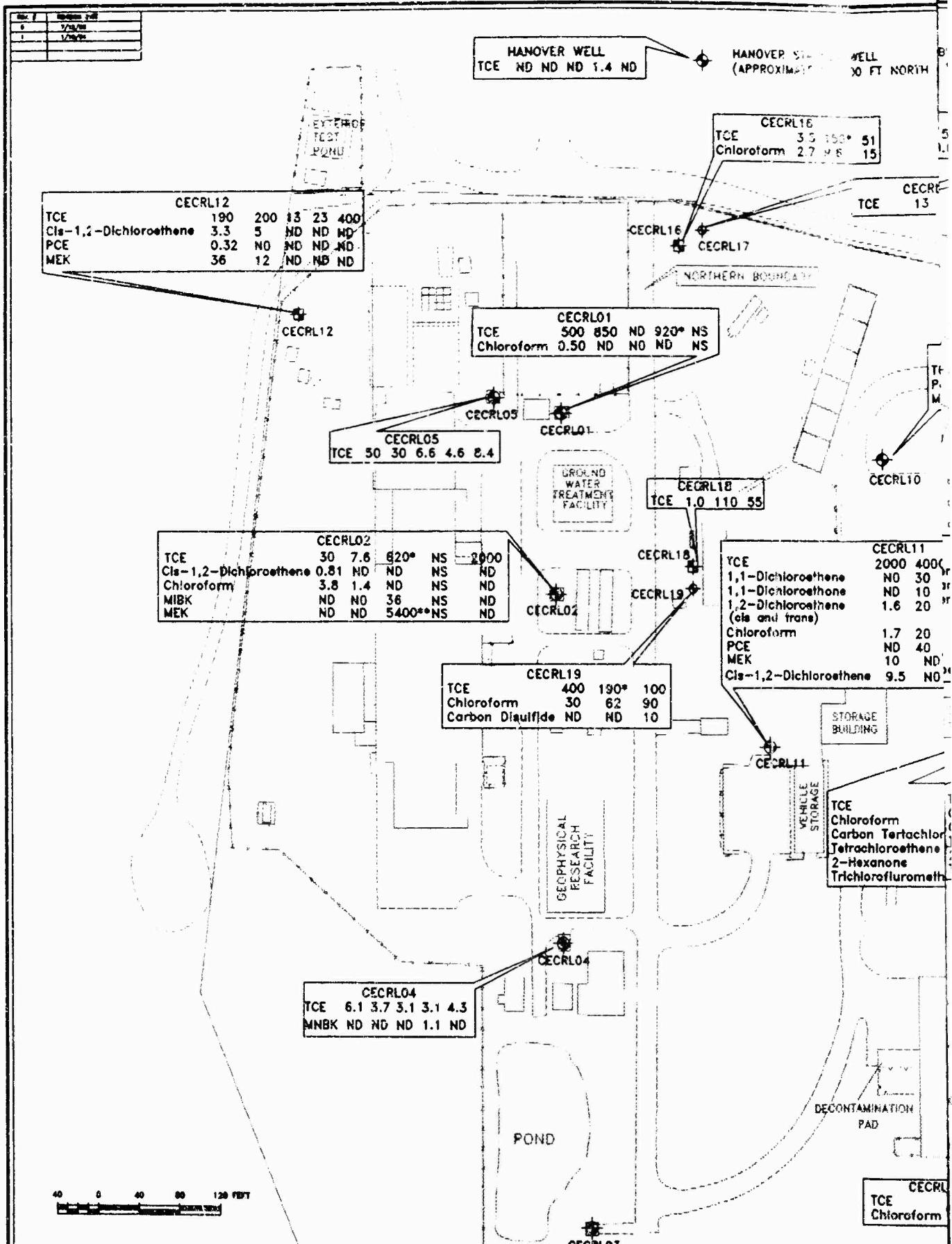
NOTES:

- (+) Indicates analyte detected by Analytical Method UGO 5 - Hydrocarbons in water by GC/CON
- Dashes indicates that the analyte is present below the detection limit; Table includes detected analytes only
- * Laboratory estimated value derived from a reported 150 GT detection

** Laboratory estimated value derived from a reported 100 GT detection

*** Detection by Analytical Method AVB - Volatile Aromatic Compounds in water by GC

Significant figures reflect dilution factor



PREPARED FOR:

USAEC

DRAWN BY: (INITIALS)

DATE:

FEB. 1994

SCALE:

AS SHOWN

DWG. NO.

67063-043

APPROVED BY: (INITIALS)

RTH BY * 100 (DEPTH OF CRATE)

50° 5
1.6 :

CECRL17
13 34 21

TCE	170	300	50	83	110
PCE	ND	ND	ND	18	ND
MEK	ND	ND	ND	44	ND

FEBRUARY
1968
EACH

000	5200*	2700*	3000
0	ND	ND	ND
0	ND	ND	ND
0	ND	ND	ND
0	ND	2.3	ND
0	ND	0.93	ND

CECRL15
TCE 41 170° 200
Chlooreform ND 3.7 ND

CECRL15
CECRL08

	CECR114		
TCE	18	160	20
Chloromethane	2.4	ND	ND
1,2-Dichloroethene	150	120	100
(cis and trans)			
Chloroform	ND	1.3	ND

	CECR08				
TCE	1000	10000	2600*	410*	6000
Chloromethane	ND	ND	1.9	ND	ND
Chloroform	ND	ND	ND	3.5	ND
Carbon Tetrachloride	ND	ND	ND	1.7	ND
Trichlorofluoromethane	ND	ND	ND	26	ND
MEK	73	ND	ND	ND	ND

	CECRLOG					
	60000	200000	100	2000°	90000	
TCE	ND	ND	ND	19	ND	
Chloroform	ND	ND	ND	7.6	ND	
Carbon Tetrachloride	ND	ND	ND	9.3	ND	
chloro- ethene	ND	ND	ND	1.7	ND	
Jetrachloroethene	ND	ND	ND	33	ND	
2-Hexanone	ND	ND	ND			
Trichlorotoluomethane	ND	ND	ND			

	CECR06				
TCE	10000	30000	2700*	48000*	7000
PCE	1000	20000	1400*	2700*	800
1,1-Dichlorethene	ND	ND	6.9	ND	ND
1,2-Dichlorethene (cis and trans)	ND	ND	54	210*	ND
1,1,2,2-Tetrachloroethane	ND	ND	ND	370*	ND

ICE ENGINEERING
FACULTY

CECRL20
TCE 19 25 35
Chloroform ND 1.5 ND

Arthur D Little

三五

EXPLANATION

 OVERBURDEN WELL LOCATION

BEDROCK WELL

ND = NOT DETECTED

* = LABORATORY ESTIMATE FROM A

REPORTED 1500 ft VALUE

REPORTED 1000T VALUE

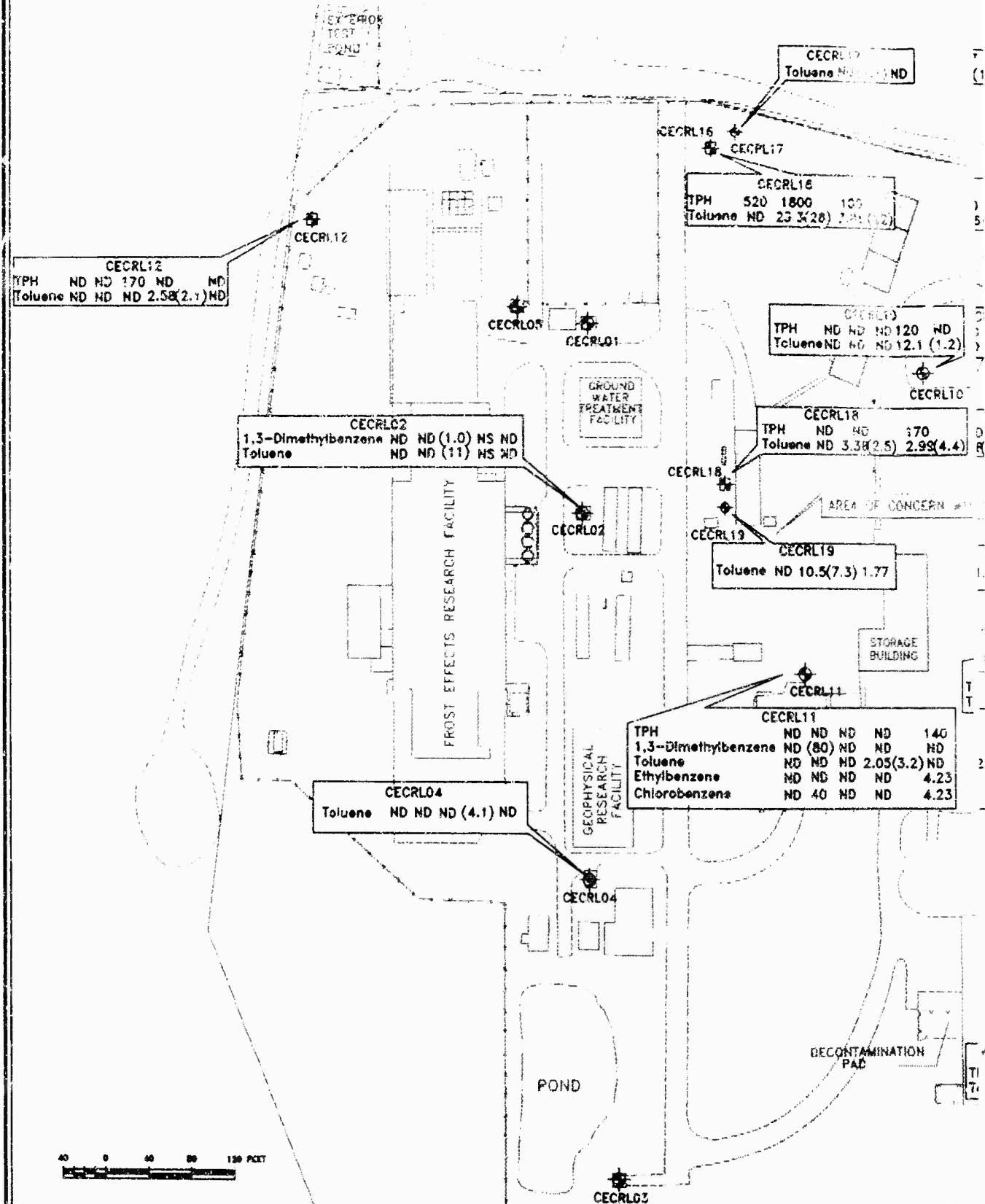
DETECTIONS ARE SHOWN FOR MODELS 1 TO 5,
EXCEPT FOR CECRL13 TO CECRL20 WHICH

EXISTS ONLY DURING

FIGURE 4-11
COLD REGIONS RESEARCH AND
ENGINEERING LABORATORY
DISTRIBUTION OF VOC
CONTAMINATION IN GROUNDED WATER

REV. #	REVISION DATE
0	1/10/94
1	2/22/94

HANOVER STATION WELL
(APPROXIMATELY) 0 FT NORTH



PREPARED FOR:

USAEC

DRAWN BY: (INITIALS)

DATE:

FEB. 1994

SCALE:

AS SHOWN

DWG. NO.
67063-042

APPROVED BY: (INITIALS)

ND BY *
NORTHLY 100' NORTH OF CRREL)

(1.1) ND

5(12)

ND
(1.2)
CRL10
ND 120 ND
ND 12.1 (1.2)

RL10
CECRL10
D 170
(2.5) 2.99(4.4)

RN #11 OF CRL104 #15

1.77

STOG
BRIE

40 ND 140
40 ND
40 2.05(3.2) ND
2.23 ND 4.23
2.23 ND 4.23

CECRL13
TPH ND ND 620
Toluene 2.97 6.45(18) 39.3(39)

CECRL07
TPH ND ND ND ND 120
Toluene ND ND ND 8.2 (15) ND

CECRL07
CECRL13

BACKGROUND
AREA 1

CECRL15
TPH 300 410 990
Toluene 9.04(8.2) 9.78(9.1) 4.78

CECRL08
TPH ND ND ND ND 140D
Toluene ND ND ND 4.50(6.8) 2.19

CECRL15
CECRL08

AREA OF CONCERN #1

CECRL14
TPH ND 110 110
Toluene ND 1.79(3.6) 11.4(10)

CECRL09
TPH ND ND 200 220 230
Toluene ND ND 3.57 3.91 4.83

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CECRL20
TPH 2700 ND ND
Toluene ND 7.20 (4.8) ND(1.3)

BACKGROUND
AREA 2

Arthur D Little

TITLE:

FIGURE 4-12
COLD REGIONS RESEARCH AND
ENGINEERING LABORATORY

DISTRIBUTION OF TPH AND BTEX
CONTAMINATION IN GROUND WATER

CECRL05
TPH 500000 2000000 400000 800000 200000
1,3-Dimethylbenzene ND ND (40) 70 (460) 31.1
Ethylbenzene ND ND (14) 20.6 (150) 9.22
Toluene ND ND (53) 100 (180) 40
Trimethylbenzenes ND (8000) ND ND ND
Xylenes(Total) ND ND (47) 70 36.2
Benzene ND ND 7.6 19 ND

ROUTE

EXPLANATION

◆ OVERBURDEN WELL LOCATION

◆ BEDROCK WELL LOCATION

ND = NOT DETECTED

() INDICATES ANALYTES DETECTED
BY GC/MS ANALYTICAL METHOD

D = DUPLICATE SAMPLE

DETECTIONS ARE SHOWN FOR SAMPLING
ROUNDS 1 TO 5 EXCEPT FOR CECRL13
TO CECRL20 WHICH EXISTED ONLY FOR
ROUNDS 3 TO 5.

ALL UNITS ARE ug/L

INITIALS) W/N EY. (INITIALS)

MSB

(INITIALS) ROVED BY: (INITIALS)

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- Trichlorofluoromethane (Freon 11)
- Carbon Tetrachloride
- Chlc.obenzene
- 1,1,1-Trichloroethane
- Chloromethane

Ice Well

Two chlorinated compounds, TCE and PCE, were detected in the Ice Well (CECRL06) in all five rounds of sampling as well as during the USAEC sampling. TCE concentrations ranged from 2,700 (round three) to 48,000 (round four) µg/L, although these values are estimated. The PCE concentrations ranged from 200 to 20,000 µg/L with the maximum level recorded during round two.

1,2-Dichloroethene (cis and trans isomers) were detected during USAEC sampling as well as during rounds three and four. The concentrations were found to be 100 µg/L during USAEC sampling, 54 µg/L during round three, and an estimated 210 µg/L during round four.

CECRL06 also yielded a detection of 1,1,2,2-tetrachloroethane during round four of sampling, with an estimated concentration of 370 µg/L. Likewise, 1,1-dichloroethene was detected during round three and yielded a concentration of 6.9 µg/L. Chloroform was detected only during USAEC sampling at a concentration of 20 µg/L.

Methylene chloride, a suspected laboratory contaminant, was detected in the Ice Well during rounds one and two of sampling at the respective concentrations of 300 and 2,000 µg/L.

It should be noted that the Ice Well was constructed as an experimental drilling test chamber and not a monitoring well. Based on comparison of the static water level inside the Ice Well, and ground water levels, exchange appears to be minimal or non-existent.

Production Wells

In the analyses of sampling from the production wells, five chlorinated compounds were detected:

- TCE
- PCE
- Cis-1,2-dichloroethene
- Chloroform
- Methylene Chloride

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TCE was found in all wells sampled with the exception of CECRL03. Wells CECRL01 and CECRL02 consistently yielded the highest concentrations, with TCE levels in CECRL01 ranging from 500 µg/L in round one to an estimated 920 µg/L in round five and TCE levels in CECRL02 ranging from 7.6 to 2,000 µg/L. CECRL04 yielded the lowest TCE levels of all the production wells with detections ranging from 3.1 to 6.1 µg/L. The TCE in CECRL05 ranged from 4.6 to 100 µg/L, with the lower levels found in the later sampling rounds and the highest level found during USAEC sampling. The concentrations found in CECRL05 decreased during the transition from rounds one and two to rounds three and four. The Hanover well yielded a detection of 1.4 µg/L during round four of sampling.

PCE was detected in CECRL02 only during the USAEC sampling at a concentration of 18 µg/L. Analyses of the other production wells yielded no PCE detections.

Cis-1,2-dichloroethene was detected during round one in CECRL02 at a low concentration. Because the reported concentration of 0.81 µg/L was less than the CRL, the concentration is estimated. During the same round, chloroform was detected in CECRL01 and CECRL02 with respective concentrations of 0.50 and 3.8 µg/L. Chloroform was also detected in CECRL02 during round two at a concentration of 1.4 µg/L.

Methylene chloride, a suspected laboratory contaminant, was detected in all five production wells and the Hanover well only during the first two rounds of sampling. The concentrations typically ranged from 3.2 to 8.4 µg/L with one sample from CECRL01 showing a detection of 200 µg/L in round two.

Monitoring Wells

In the analyses of sampling from CRREL monitoring wells, 13 chlorinated compounds were detected:

- TCE
- PCE
- Trichlorofluoromethane (Freon 11)
- Carbon tetrachloride
- Chlorobenzene
- 1,1-dichloroethene (1,1-DCA)
- 1,1-dichloroethene
- 1,1,1-trichloroethane
- Cis-1,2-dichloroethene
- 1,2-Dichloroethene (cis and trans)
- Chloroform
- Chloromethane
- Methylene Chloride

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TCE appeared as the prominent contaminant in the monitoring wells at CRREL. This compound was detected in all of the monitoring wells on the site, with concentrations ranging from 1.0 to 200,000 µg/L. The highest concentrations were detected in CECRL08 and CECRL09, the overburden wells closest to the Ice Well, and in CECRL11, a middle terrace overburden well. CECRL09 yielded the maximum concentrations with a range from 100 to 200,000 µg/L. CECRL08 yielded a range of 410 to 10,000 µg/L. CECRL11 yielded consistent detections with a range of 2,000 to an estimated 5,200 µg/L. CECRL10, a middle terrace overburden well, showed relatively consistent TCE concentrations, with a range of 60 to 300 µg/L. Well CECRL17, a lower terrace overburden well at the northern perimeter of the property, showed relatively consistent TCE concentrations of 13, 34, and 21 µg/L, respectively, during the three rounds of sampling. Well CECRL19, a lower terrace overburden well located near the greenhouse, also showed consistent TCE concentrations, with a range of 100 to 400 µg/L during the three rounds it was sampled. Well CECRL12, a lower terrace well at the northeast corner of the property, is a water table well completed in bedrock. TCE concentrations at this well ranged from 13 to 400 µg/L, with rounds three and four showing the lowest concentrations.

Wells CECRL07 and CECRL20 were installed initially to monitor background ground water quality. However, both wells have consistently shown TCE in samples. Concentrations between 5.9 and 95 µg/L were observed in samples from CECRL07. Samples from CECRL20 showed concentrations of 19, 25 (28 in the duplicate), and 35 µg/L in rounds three, four, and five, respectively.

The five bedrock wells all showed TCE in each of the three rounds of sampling. Samples from CECRL15 showed the highest concentrations of TCE at a range of 41 to 200 µg/L. Wells CECRL14 and CECRL16 produced samples showing TCE concentrations of 3.5 to 170 µg/L. Samples taken during round four showed the highest concentrations in wells CECRL14 and CECRL16 (160 and 170 µg/L, respectively). Wells CECRL14 and CECRL15 are the bedrock couplets to wells CECRL08 and CECRL09, the two wells that showed the highest concentrations of TCE in the overburden.

In addition, the Goodrich and Peacock wells in Vermont both yielded TCE detections during USAEC sampling. TCE was found in the Goodrich well at a concentration of 17 µg/L and in the Peacock well at a concentration of 24 µg/L.

Well CECRL18, the bedrock couplet to CECRL19, showed a TCE concentration range of 1.0 to 110 µg/L, and the background monitoring well, CECRL13, showed a consistent concentration of TCE with a range of 3.2 to 4.9 µg/L.

PCE was detected in three water table monitoring wells (CECRL09, CECRL10, and CECRL11) and one bedrock monitoring well (CECRL12). During round one, PCE

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was detected in one monitoring well, CECRL12, at a concentration of 0.32 µg/L. In the following round, PCE was detected in CECRL11 at a level of 40 µg/L. During round four, PCE was detected in CECRL09, CECRL10, and CECRL11 at concentrations of 9.3, 18, and 0.93 µg/L, respectively.

During the fourth sampling round, trichlorofluoromethane (Freon 11) and carbon tetrachloride were detected in CECRL08 and CECRL09, the two overburden wells nearest to the Ice Well. The concentrations remained consistent between the two wells with trichlorofluoromethane found at 26 µg/L in CECRL08 and 33 µg/L in CECRL09, and carbon tetrachloride found at 1.7 µg/L in CECRL08 and 7.6 µg/L in CECRL09. Because trichlorofluoromethane can be a laboratory introduced compound, it is unclear that these low concentrations truly reflect ground water conditions at CECRL08 and CECRL09.

CECRL11, a middle terrace overburden well, yielded detections of chlorobenzene, 1,1-dichloroethane, 1,1-dichloroethene, and 1,1,1-trichloroethane. Chlorobenzene and 1,1-dichloroethane were detected during round two at the respective concentrations of 40 and 10 µg/L. During rounds two and four, 1,1-dichloroethene was detected at concentrations of 30 and 2.6 µg/L, respectively, with the latter detection being found in a duplicate sample. During round four, 1,1,1-trichloroethane was detected at a concentration of 1.5 µg/L in a duplicate sample.

CECRL11 also yielded a detection of cis-1,2-dichloroethene at a concentration of 9.5 µg/L during the first sampling round. Cis-1,2-dichloroethene was found in CECRL12 at concentrations of 3.3 and 5.0 µg/L during sampling rounds one and two, respectively.

In CECRL11, 1,2-dichloroethene isomers (cis and trans) were detected during rounds one, two, and four, and in CECRL14 they were detected during rounds three, four, and five. The concentrations ranged from 1.6 to 20 µg/L in CECRL11 and 100 to 150 µg/L in CECRL14.

Chloroform was detected in 8 of the 14 CRREL monitoring wells. The compound was detected in CECRL08, CECRL09, CECRL11, CECRL14, CECRL15, CECRL16, CECRL19 and CECRL20 during round four. Detections were also found in rounds three, four, and five for CECRL16 and CECRL19, and in rounds one and two for CECRL11. All concentrations remained consistently in the range between 1.3 to 90 µg/L, with the highest concentrations being found in CECRL19.

It should be noted that many of the compounds detected at lower concentrations (i.e., 1,2-dichloroethene isomers (cis and trans), cis-1,2-dichloroethene and chloroform) are believed to be environmental breakdown products of PCE, TCE, 1,1,1-trichloroethane, and carbon tetrachloride.

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Chloromethane was found in CECRL08 and CECRL14 at concentrations of 1.9 and 2.4 µg/L. Both detections were during the third round of ground water sampling.

Methylene chloride, a suspected laboratory contaminant, was detected in all of the overburden monitoring wells with the exception of CECRL17, CECRL19, and CECRL20. Concentrations ranged from 1.2 to 9,000 µg/L, with the detections in general derived from rounds one and two of sampling. Well CECRL13 was the only bedrock well to show methylene chloride, with a concentration of 2.6 µg/L detected in round four.

4.5.2 Nature and Extent of Non-chlorinated Compound and TPH Contamination

In the analyses of samples of CRREL ground water, 11 non-chlorinated compounds were detected:

- Trimethylbenzene
- 1,3-Dimethylbenzene
- 1,2-Dimethylbenzene
- Benzene
- Ethylbenzene
- Toluene
- Xylenes (total)
- Methyl ethyl ketone (MEK)
- Methyl-n-butyl ketone (MNBK)
- Methylisobutyl ketone (MIBK)
- TPH

Table 4-7 summarizes the detections of non-chlorinated compounds found on the site.

Ice Well

The Ice Well was sampled during USAEC sampling and all five RI sampling rounds. Aromatic hydrocarbons and TPH were detected in samples from both investigations.

The aromatic hydrocarbons 1,3-dimethylbenzene, ethylbenzene, toluene, and xylenes (total) were detected in CECRL06 during rounds three, four, and five. Concentrations of 1,3-dimethylbenzene ranged from 31.1 to an estimated 460 µg/L and concentrations of ethylbenzene ranged from 9.22 to 150 µg/L. Toluene detections ranged from 40 to an estimated 180 µg/L while xylenes (total) detections yielded a range of 36.2 to 70 µg/L. The lower concentrations of all compounds were detected during round five, all detections from round three were found using the GC/MS analytical method, all detections from round five were found using the GC analytical method and detections from round four were found using both analytical methods. The compound 1,3-dimethylbenzene was also detected during USAEC sampling at a concentration of 100 µg/L using the GC/MS method.

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Trimethylbenzene, 1,2-dimethylbenzene, and benzene were detected by the GC/MS method only. The compound 1,2-dimethylbenzene was detected during USAEC sampling at a concentration of 200 µg/L. Trimethylbenzene was detected during USAEC sampling and round 1, at respective concentrations of 500 and 6,000 µg/L. Benzene was detected during rounds three and four at concentrations of 7.6 and 19 µg/L, respectively.

TPH analyses of CECRL06 samples yielded detections in all rounds except two. The concentrations of TPH found at this location ranged from 200,000 µg/L during round five to 800,000 µg/L during round four.

Production Wells

In the analyses of samples from CRREL production wells, five non-chlorinated compounds were detected:

- Methyl ethyl ketone (MEK)
- Methylisobutyl ketone (MIBK)
- Methyl-n-butyl ketone (MNBK)
- Toluene
- 1,3-Dimethylbenzene

MEK and MIBK were detected in CECRL02 during sampling round three. MEK was found at an estimated concentration of 5,400 µg/L. MIBK was detected at a concentration of 36 µg/L. CECRL02 was unable to be sampled during round four. Another ketone, MNBK, was found in CECRL04 during round four at a concentration of 1.1 µg/L.

Toluene and 1,3-dimethylbenzene were detected using the GC/MS analytical method. Toluene was detected in CECRL02 during round three at a concentration of 11 µg/L and in CECRL04 during round four at a concentration of 4.1 µg/L. The compound 1,3-dimethylbenzene was detected in CECRL02 during round three at a concentration of 1.0 µg/L.

TPH was not detected in the production wells.

Monitoring Wells

Seven compounds were found in samples from the monitoring wells at CRREL:

- TPH
- Methyl ethyl ketone (MEK)
- Methyl-n-butyl ketone (MNBK)
- Toluene
- Ethylbenzene

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- 1,3-Dimethylbenzene
- Chlorobenzene

In the overburden wells, TPH was detected at 200 to 230 µg/L in CECRL09 for rounds three, four, and five. TPH was also detected in CECRL10 during round four, in CECRL11 and CECRL07 during round five, and CECRL12 during round three, with all detected concentrations ranging from 120 to 170 µg/L. Background well CECRL20 revealed 2,700 and 130 µg/L TPH during rounds three and four respectively, with the 130 µg/L concentration being detected in a duplicate sample. TPH was also detected in a duplicate sample of CECRL08 at a concentration of 140 µg/L during round five.

Detection of TPH in the bedrock wells was more consistent than in overburden wells. Wells CECRL15 and CECRL16 yielded TPH in rounds three, four, and five. Well CECRL16 showed the highest levels, ranging from 100 to 2,000 µg/L. Well CECRL14 yielded detections in rounds four and five with a consistent concentration of 110 µg/L. Bedrock wells CECRL13 and CECRL18 also showed concentrations of TPH at 620 and 170 µg/L, respectively, in round five.

Two ketones, MEK and MNBK, were detected in five of the monitoring wells at the CRREL site. MEK was found primarily in the overburden wells, with detections in CECRL07, CECRL08, CECRL10, and CECRL11. CECRL12 was the only bedrock well to yield a MEK detection. The concentrations consistently remained in the 10 to 73 µg/L range. All detections were found in rounds one and two of sampling, with the exception of CECRL10, whose detection was found during the analysis of round four. The second detected ketone, MNBK, was found in CECRL09 during round four of sampling at a level of 17 µg/L. These ketone detections, with the exception of the CECRL10 concentration, were reported as being below the CRL, and thus may not be representative of actual site conditions (see Section 2.6).

Toluene was another commonly detected compound in the CRREL wells, with all monitoring wells yielding detections during rounds three or four of sampling. Toluene concentrations generally remained below 13 µg/L, using the GC analytical method, with the exception of two bedrock wells CECRL13 and CECRL16, which were found to have respective concentrations ranging up to 39.3 to 23.3 µg/L.

Toluene concentrations detected with the GC/MS method generally correspond to GC results, with detections ranging from 1.1 µg/L in CECRL17 to 39 µg/L in CECRL13. A complete listing of all detections is found in Table 4-7.

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Ethylbenzene was detected in CECRL11 at a concentration of 4.23 µg/L during round five. The compound 1,3-dimethylbenzene was also detected by GC/MS during round two in CECRL11, at a concentration of 80 µg/L.

Chlorobenzene was detected in CECRL11 during round two at a concentration of 40 µg/L, using the GC/MS analytical method.

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5.0 Contaminant Fate and Transport

The historical use and release of chemicals at CRREL has resulted in soil and ground water contamination by VOCs, BTEX, and TPH. The contaminant characteristics and the physical setting of the site play crucial roles in contaminant fate and transport. This section discusses the characteristics of the site and organic chemicals that may affect the fate and transport of contaminants at the site.

5.1 Contaminant Fate and Transport Characteristics

Contaminant fate and transport is controlled by physical and chemical properties of both the contaminant and the media in which the contaminant resides. Properties of the contaminant that will affect fate and transport include:

- Solubility
- Vapor Pressure
- Henry's Law Constant
- Sorption
 - Soil Partition Coefficient (K_d)
 - Organic Carbon/Water Partition Coefficient (K_{oc})
 - Log of Octanol/Water Partition Coefficient (K_{ow})
- Density
 - Non-Aqueous Phase Liquids (NAPLs)
- Viscosity
- Degradation Potential
 - Abiotic Degradation
 - Biotic Degradation (Biodegradation)

Properties of the media that will affect fate and transport include:

- Method of contaminant disposal
- Soil permeability
- Soil porosity
- Presence of clays
- Ground water velocity and direction
 - Diffusion/dispersion
 - Advection
- Reduction or oxidation potential
- Presence and character of bedrock fractures
- Presence and abundance of microorganisms

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Values of some of these properties for chemicals of concern detected at the CRREL site are listed in Table 5-1. These values were derived under ideal circumstances and, therefore, do not necessarily represent site conditions, but can be used as a relative guide to estimate the propensity of a contaminant to persist, migrate, or degrade in the environment.

The information derived from the listed contaminant properties, when applied to the physical setting, will allow for the determination of contaminant migration pathways, predict likely contaminant fate scenarios, and identify those contaminants that are likely to pose the most significant threat to human health and the environment. The characteristics pertinent to the CRREL site are described below.

Solubility: Solubility is the maximum concentration a chemical will achieve in pure water at a specific temperature and pressure. Listed values were generated at one atmosphere, 20 to 30 degrees Celsius. In general, a higher solubility indicates that a contaminant is hydrophilic; it will tend to remain in solution and will be more mobile in water than a compound with low solubility. A low solubility indicates that the compound is hydrophobic and will tend to partition to another phase, such as air or organic matter. Compounds detected at CRREL generally have high solubilities. The detected aromatic hydrocarbons have a lower range of solubilities (152 to 1,780 mg/L) than the halogenated aliphatic hydrocarbons (150 to 8,000 mg/L) and the ketones (19,000 to 268,000 mg/L).

The presence of compounds at or near their solubility limit may indicate that the compound is in a non-aqueous phase, i.e., it exists as "pure" product. This is called non-aqueous phase liquid (NAPL). However, some sources (Cherry and Feenstra, 1991) estimate that a NAPL, specifically a heavier than water NAPL or dense non-aqueous phase liquid (DNAPL), can be associated with contaminant plume concentrations as low as 1 percent of its solubility. When a compound is present as NAPL, the mechanisms that control its fate and transport are not the same as those that control the fate and transport of compounds in solution.

TCE concentrations in some wells (CECRL08, CECRL09, and the Ice Well) were above 1 percent of the solubility value, indicating the potential for DNAPL at the site.

Vapor Pressure: The vapor pressure of a compound is the pressure exerted when a solid or liquid is in equilibrium with its own vapor. A compound's vapor pressure is a function of temperature and indicates its relative propensity to volatilize or evaporate at varying temperature levels. The values that are presented in Table 5-1 were generally measured at 20 to 30 degrees Celsius. In general, compounds with vapor pressures less than 10^{-7} mm Hg will remain in liquid or solid state at normal conditions; compounds with vapor pressures greater than 10^{-2} mm Hg are usually

Table 5-1: Physical and Chemical Properties of Detected Chemicals of Concern, CRREL

Compound	Gross Density (g/ml)	Solubility (mg/l)	Henry's Constant (mm-m ³ /M)	Physical/Chemical Properties		
				Log Kow	Koc	Vapor Pressure (mmHg)
VOLATILE ORGANIC COMPOUNDS						
Chlorinated Aromatics Chlorobenzene	112.56	1.11	500	3.72E-03	2.84	3.30E+02
Halogenated Aromatics 1,1,1-Dichloroethane	133.40	1.34	1495	1.70E-02	2.49	1.79E+02
1,1,1-Dichloroethane ^a	99.00	1.17	5500	4.31E-03	1.79	30
1,1-Dichloroethylene ^b	97.00	1.22	250	3.00E-02	1.48	1.82E+02
1,2-Dichloroethylene ^c	97.00	1.28	3500	7.50E-03	2.09	49
Carbon Tetrachloride	153.82	1.59	1160	3.00E-02	2.64	1.10E+02
Chloroform	119.38	1.49	8000	3.39E-03	1.97	3.10E+02
Chloromethane/Methyl Chloride	51.00	0.92	6500	C 4.40E-02	0.95	3.50E+01
Tetrachloroethylene/Tetrachloroethene	166.00	1.62	150	C 2.59E-02	2.80	3.84E+02
Trichloroethylene/Trichloroethene	131.40	1.53	1100	C 1.03E-02	2.42	1.01E+02
Trichlorofluoromethane/Fraction 11	137.40	1.50	1100	C 5.83E-02	2.53	1.59E+02
Water Solubilities						
Methyl Ethyl Ketones/ 2-Butanone	72.10	0.90	268000	C 2.74E-05	0.26	7.75E+01
Methyl Isobutyl Ketone/ 4-methyl-2-pentanone	100.16	0.80	19000	C 1.40E-04	1.19	1.90E+01
Methyl-N-Buyl Ketone/ 2-Hexanone	100.20	0.92	350000	d ..	1.39	2.00E+00
BTEX COMPOUNDS						
1,3-Dimethylbenzene/m-xylene	106.17	0.86	161	7.19E-03	3.20	1.66E+02
Benzene	78.11	0.88	1780	5.50E-03	2.13	8.30E+01
Ethylbenzenes	106.20	0.86	152	8.40E-03	3.15	2.50E+02
Toluene	92.10	0.88	526	6.60E-03	2.73	9.50E+01
Xylenes (total) ^d	106.20	0.86	160	6.82E-03	3.20	2.40E+02

Refer encas.

Unpublished data obtained from Envirodata database

* - data derived from Ecotox and Environment Table 7-1, October 1992

** - data not found in reference stated below

Cahn - gram mol/cd for weight

BTX - benzene, toluene, ethylbenzene, xylyne

Ecotox - Log of Octanol/Water Partition Coefficient

Koc - Organic Carbon/Water Coefficient

BTX - benzene, toluene, ethylbenzene, xylyne

Log Kow - Log of Octanol/Water Partition Coefficient

Koc - Organic Carbon/Water Coefficient

BTX - benzene, toluene, ethylbenzene, xylyne

Ecotox - Log of Octanol/Water Partition Coefficient

Koc - Organic Carbon/Water Coefficient

BTX - benzene, toluene, ethylbenzene, xylyne

Log Kow - Log of Octanol/Water Partition Coefficient

Koc - Organic Carbon/Water Coefficient

BTX - benzene, toluene, ethylbenzene, xylyne

Ecotox - Log of Octanol/Water Partition Coefficient

Koc - Organic Carbon/Water Coefficient

BTX - benzene, toluene, ethylbenzene, xylyne

Log Kow - Log of Octanol/Water Partition Coefficient

Koc - Organic Carbon/Water Coefficient

BTX - benzene, toluene, ethylbenzene, xylyne

Ecotox - Log of Octanol/Water Partition Coefficient

Koc - Organic Carbon/Water Coefficient

BTX - benzene, toluene, ethylbenzene, xylyne

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found in the gaseous state under normal conditions. The VOCs detected at CRREL have vapor pressures between 2 and 4,300 mm and, therefore, will tend to evaporate.

Henry's Law Constant: The Henry's Law constant (H) is a relative measure of volatility expressed as a ratio of the concentration of a given chemical in air to its concentration in water.

$$H = [\text{air}]/[\text{water}]$$

where: [air] = concentration of the chemical in air
[water] = concentration of the chemical in water

Henry's Law constants are valid for dilute solutions at equilibrium under non-ideal conditions. The larger the numerical value for the constant, the greater the tendency for that compound to volatilize. The Henry's Law constant accounts for the solubility and vapor pressure of each compound. These constants become a less valid measure of volatility for chemicals with low vapor pressures and low water solubilities. The Henry's Law constant can range over eight orders of magnitude, from 10^{-7} to 10^8 (atm)(m³)/mol at ambient temperatures (Arthur D. Little, 1985). In general, a contaminant with a Henry's Law constant of less than 5×10^{-5} (atm)(m³)/mol will remain dissolved in water, while a contaminant with a Henry's Law constant greater than 5×10^{-3} (atm)(m³)/mol will tend to volatilize (Olson and Davis, 1990). Based on their Henry's Law Constants, most of the VOCs detected at CRREL will volatilize from water while the ketones will remain dissolved.

Sorption: The sorption of contaminants onto soil and aquifer material is generally simplified by assuming the occurrence to be instantaneous, reversible, and independent of contaminant concentration. Usually, organic matter is the predominant soil component that influences adsorption of organic chemicals (Dragun, 1988). In ground water, sorption causes the contaminant plume to be differentiated based upon the sorptive affinities of the various chemicals in the plume. The velocity of a retarded solute can be a fraction of the velocity of ground water. As such, although several contaminants may be released into an aquifer at the same time, they often do not travel at the same rate or appear simultaneously at receptor sites. Similarly, breakdown products of primary contaminants may not travel at the same rate as the parent compound. The primary contaminants at CRREL are poorly sorbed to soil.

The phenomenon of slowing a contaminant's rate of transport from the source area by sorption is referred to as retardation. Significant factors in retardation include the presence of organic matter and clay. At CRREL, AOC 9 and the perched zone of the lower terrace are situated in clay rich overburden; hence, sorption and thus retardation must be considered. Moreover, the potential underestimation of retardation is a factor that must be considered in assessing fate and transport.

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Many equations have been derived to assist in predicting the tendency of a contaminant compound to adsorb to soil and aquifer materials (partitioning coefficients). The relationships and the parameters involved are briefly discussed below. They are generally appropriate for systems that contain at least 0.1 percent organic carbon and are not dominated by high percentages of clay material.

Soil Partition Coefficient (K_d): The soil partition coefficient (K_d) is defined as the ratio of the concentration of organic chemicals adsorbed onto soil to its concentration in solution at equilibrium and is typically measured for a specific soil or chemical in a laboratory using batch equilibrium tests. K_d is an indicator of a compound's tendency to partition to soil.

Though the partition coefficient for a specific compound is directly proportional to the amount of organic carbon in a given soil matrix, the percent of organic matter in the soil is not considered during the K_d measuring process. The K_d for a specific chemical will vary based upon the soil, sediment, or aquifer material and will also vary depending upon conditions such as pH, redox potential, and major ion composition. The K_d for a specific soil, sediment, or aquifer material will vary for different chemicals.

Organic Carbon/Water Partition Coefficient (K_{oc}): The organic carbon/water partition coefficient (K_{oc}) is a chemical-specific measure of the relative propensity of a non-polar compound to adsorb onto soil and sediment. K_{oc} is defined as the ratio of the measured concentration of a compound adsorbed to the soil phase to its concentration in the aqueous phase. K_{oc} has been described as K_d normalized for the amount of organic matter in soil. Because it is normalized for organic content, values calculated for a specific chemical are relatively constant and reasonably independent of the soil or sediment present. It has been noted in studies of sorption of a wide variety of compounds by various soils and sediment, that when there is sufficient organic matter, the organic matter dominates or controls sorption.

A compound with a high K_{oc} is more likely to adsorb onto and become immobile in soil, whereas a compound with a low K_{oc} is considered relatively more mobile through a soil or sediment matrix. Values of K_{oc} may range from 1 to 10^7 (Lyman et al., 1982). A K_{oc} value of less than 10 indicates that the compound would likely pass through a soil matrix without adsorbing to any organic material; K_{oc} values from 150 to 2,000 indicate compounds with relatively medium to low propensities to migrate. Compounds with K_{oc} values of 75,000 and greater are considered immobile in soil (Dragun, 1988). In general, VOCs detected at CRREL have low values (4.5 to 364) of K_{oc} and will, therefore, not tend to sorb onto organic material. The semivolatiles have higher K_{oc} values (1,030 to 5,500), and thus, will be more likely to sorb onto organic material.

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Octanol/Water Partition Coefficient (K_{ow}): The octanol/water partition coefficient (K_{ow}) is a laboratory-derived measure of the distribution of a compound between octanol and water and is used as a general indicator of a compound's affinity for organic material. A compound is placed in a beaker with octanol and water, mixed, and allowed to come to equilibrium. The water and octanol are analyzed to determine the amount of compound present.

The K_{ow} is generally expressed as a log value. A higher log K_{ow} value (greater than four) indicates that a compound is more likely to adsorb onto organic material; these compounds generally have lower water solubilities and are hydrophobic. Conversely, a low log K_{ow} (value less than one) indicates that the compound is less likely to be sorbed onto organic material; these compounds typically have higher water solubilities and are hydrophilic (Lyman et al., 1982). Compounds with low log K_{ow} values, therefore, will tend to be more mobile in the environment. Volatile organics typically have log K_{ow} values of less than 4 and will tend to solubilize in water rather than sorb onto organic material. In general, semivolatiles, pesticides, and PCBs have higher log K_{ow} values (>4) and will tend to sorb onto organics. The values of log K_{ow} for compounds detected at CRREL range from .26 to 3.20 and thus indicate a tendency to solubilize in water.

Density: The density of a compound is the ratio of its mass to its volume. The density of a compound relative to water (i.e., specific gravity) can have a significant effect on its migratory route from the source area, particularly when the compound is in its non-aqueous phase. Most halogenated volatile organics, such as trichloroethylene (TCE), carbon tetrachloride, 1,1,1-trichloroethane (1,1,1-TCA), and semivolatiles, have densities greater than water. Aromatic compounds, such as benzene, toluene, and xylenes, have densities less than water.

The primary factor controlling migration of dissolved plumes of ground water contamination tends to be local hydraulic gradients. At elevated contaminant concentrations, however, these dissolved plumes may attain a density that can challenge the hydraulic gradient. The plume may sink or rise over a distance from the source area depending on the density of the plume's constituents. Density is a prominent issue in fate and transport if the contaminant is found in the NAPL form. As NAPL may be present at CRREL, density is expected to play a role in contaminant plume migration.

Viscosity: Viscosity represents the resistance of a fluid to flow under an applied force. A fluid that has a relatively high viscosity or is more viscous than water tends to flow more slowly than water. A fluid that has a low viscosity or is less viscous than water will tend to flow more easily through an aquifer or fracture. Many of the compounds that may occur as DNAPLs have a very low viscosity, which increases their ability and tendency to migrate in the subsurface. Compounds with a viscosity

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less than water will infiltrate into soil notably faster than water. Several common DNAPL compounds, such as TCE, 1,1,1-TCA, and carbon tetrachloride, for example, will flow 1.5 to 3 times as fast as water (Huling and Weaver, 1991). Viscosity is primarily an issue if the contaminant is present in the NAPL form. As this is a possibility at CRREL, viscosity may play a role in the fate and transport of contaminants at the site.

Degradation: Contaminant degradation can occur via many different pathways and mechanisms, both biotic (through biological activity) and abiotic (without biological activity). Generally, the environment will dictate or indicate the type of reaction that is most likely to occur.

- **Abiotic Degradation:** Abiotic degradation occurs when compounds are altered without microbial intervention. Abiotic mechanisms that can result in the degradation of a contaminant include, but are not limited to, denitrification, photodegradation, reduction/oxidation, and hydrolysis. Photodegradation and hydrolysis are not thought to be important in the fate and transport of compounds in ground water (Olsen and Davis, 1990); however, they may be important in surface water environments.

Iron and certain transition metals, such as cobalt and chromium, may play a significant role in the fate of contaminants in ground water since these metals will interact with organic molecules or macromolecules, and can transform (reduce) certain halogenated aliphatic organic compounds abiotically (i.e., without active mediation by microorganisms).

- **Biotic Degradation:** Biotic degradation (biodegradation) occurs when a microorganism changes the structure of a compound by metabolizing it. As in abiotic degradation, compounds are transformed from one form into a smaller, less complex, and usually more mobile form that is sometimes more toxic than the original.

The existence and type of microbes in the soil and ground water can have a significant effect on the contaminant profile. Bacterial population profiles vary seasonally and determine the intermediate biodegraded halogenated organic compound profile in the system. For example, some bacteria will reduce all tetrachloroethane present at a given time, with the formation of only intermittent trace amounts of lower halogenated compounds. Other bacterial profiles will reduce the tetrachlorethane producing all possible intermediate products. Certain compounds are more readily used as nutrients by indigenous bacteria.

Microbes require specific conditions for their colonies to thrive. Some prefer to utilize oxygen and others prefer methane. Slight changes in the environment can

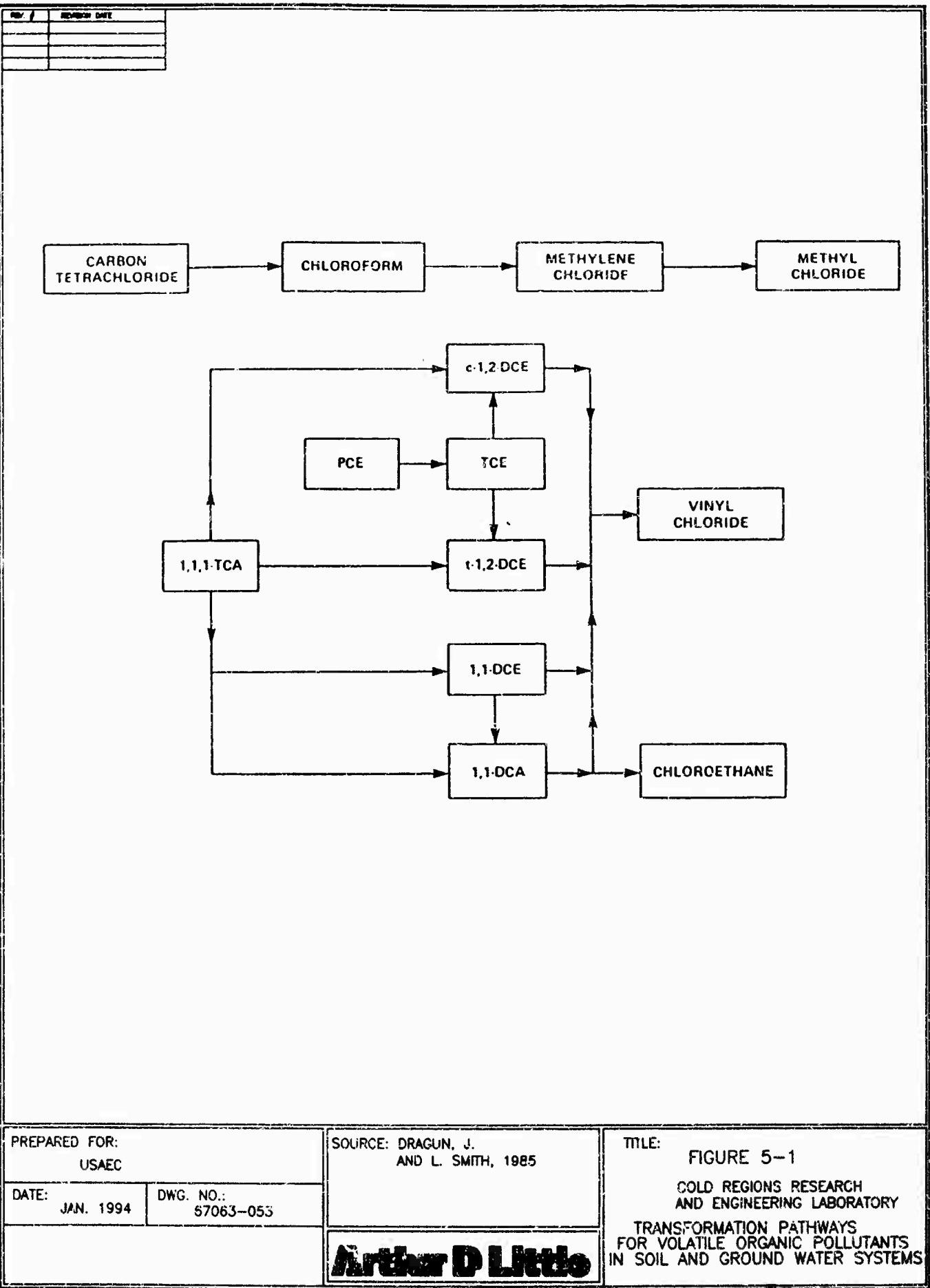
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enhance or inhibit biodegradation. Extremes of temperature, pH, salinity, osmotic or hydrostatic pressures, radiation, contaminant concentrations, and/or the presence of heavy metals, such as chromium or other toxicant materials, can adversely influence and even limit the rate of microbial growth and/or substrate utilization. Contaminant concentration is an important factor in determining whether or not biodegradation will occur. For example, 500 mg/L TCE will be toxic to microbes; however, they seem to be able to exist in ground water with 50 mg/L TCE (Fliermans et al., 1988). Solubility is also a factor in biodegradation. In general, compounds that are more soluble are more readily available for the microbes to metabolize and degrade.

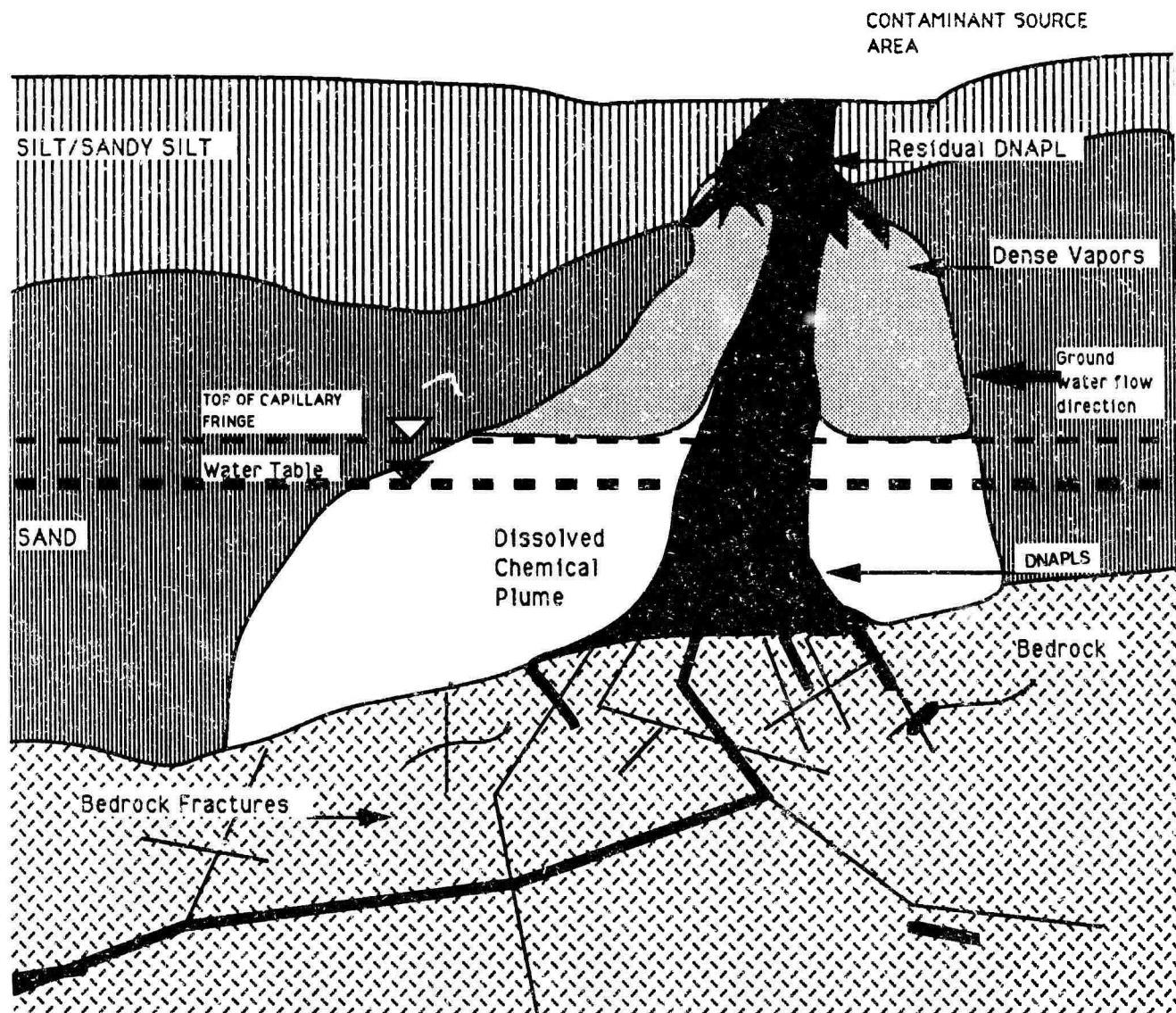
Microbial colonies have unique nutrient requirements and will prefer some compounds to others. Halogenated compounds are generally found to be more readily degraded in anaerobic environments, whereas the degradation of aromatic compounds is favored in aerobic environments. However, all degradation pathways are not favored equally. Anaerobic biodegradation of either TCE or tetrachloroethene (PCE) produces cis-1,2-dichloroethene (cis-1,2-DCE) over trans-1,2-dichloroethene (trans-1,2-DCE), a more toxic compound by a factor of 25 or more. Figure 5-1 shows some transformation pathways for common chlorinated compounds.

There is no direct evidence from sampling that microorganisms capable of biodegradation of the primary contaminants at CRREL are present in the soil or ground water. However, based on the presence of intermediate biotic breakdown products observed in six wells, and chloroform in eight additional wells, biotic degradation may be a significant process at CRREL.

Diffusion and Dispersion: Contaminant plumes will tend to expand laterally and vertically due to the phenomenon of molecular diffusion and dispersion. Molecules spread out to equalize the concentration in all parts of the system. Molecular diffusion is the mechanism by which clay liners are eventually breached, as contaminants will diffuse through the clay matrix as the result of concentration gradients. This process is very slow and is not generally considered a significant transport mechanism for ground water environments except where ground water flow is extremely slow and contact is prolonged. The low permeabilities and intermittent clay lenses in the overburden at CRREL may make diffusion and dispersion locally significant.



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Arthur D. Little

TITLE:
FIGURE 5-2
COLD REGIONS RESEARCH
AND ENGINEERING LABORATORY
MOVEMENT OF DNAPL
INTO THE SUBSURFACE

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completely dissolved, or they encounter an impermeable barrier or fracture in bedrock. If they are lighter than water (such as the petroleum hydrocarbons) they will collect at the top of the water table and slowly be dissolved into the ground water or move with the ground water as a separate phase. There is no evidence that lighter than water separate phase petroleum hydrocarbons occur in the main aquifer at CRREL.

Once in the ground water the contaminants will move by advection, dispersion, and gravity. The relatively low hydraulic conductivities and ground water velocities in the overburden will tend to encourage diffusion and sorption to aquifer materials, thus increasing retardation. In the dissolved phase the contaminants will move in the direction of ground water flow, generally toward the south and east. Downward vertical hydraulic gradients throughout most of the site will draw the contaminants into the deeper portion of the aquifer where they will be less likely to volatilize into the soil, and will travel longer distances before concentrations are dispersed below detection levels. The bottom of the overburden aquifer is composed of larger grains and likely has increased porosity and hydraulic conductivity. Contaminants reaching the lower portion of the aquifer are more likely to migrate further at a faster rate than those in the silty upper portion of the aquifer.

The flow of contaminants due to density plumes is controlled by gravity and permeability. A high density plume of dissolved chlorinated aliphatic hydrocarbons will at first tend to migrate in the direction of ground water flow but because of the higher density of the plume, it will sink to the lower portion of the aquifer into the more permeable zone. Once at the bottom of the overburden, the plume may continue to travel along bedrock topography in the direction of downward slope, or it may enter the fracture zone at the top of bedrock, or settle in an impermeable depression in bedrock. The direction of downward slope of the bedrock may be considerably different from the direction of ground water flow. At CRREL, there is an apparent bedrock low oriented approximately north-south in the center portion of the site where contaminants would be most likely to travel and potentially settle.

Separate phase contaminants will follow the same pattern as the high density plume, however, the lateral component of migration will be less significant. Contaminants released into the aquifer directly as a separate phase will respond little to the ground water flow direction and will follow along impermeable layers such as clay or bedrock until dissolved, captured by fractures, or settled in bedrock lows.

In summary, transport of contaminants through the overburden portion of the aquifer will expand the plume laterally and vertically through advection, dispersion, and gravity. Contaminants are not likely to partition to the soil grains, tending, rather, to remain in ground water. The plume may expand in directions other than the primary direction of ground water flow.

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5.3.3 Bedrock

Flow of contaminants in bedrock will occur if bedrock is sufficiently permeable and contaminant densities are greater than water or if there is downward vertical flow. Conditions at CRREL satisfy all of these requirements. Fracture zones in bedrock trend primarily to the northwest with a second set of fractures oriented northeast. Bedrock studies on the west side of the Connecticut River also show dominant fracture directions of northwest and northeast. Fracture apertures (which may include fracture zones) measured from geophysical logs at CRREL are from 0.16 to inches, with most fractures in the 0.16- to 0.5-inch range. The bedrock itself appears to be impermeable. Flow in fractured bedrock is primarily due to advection, as dispersion is relatively insignificant except at fracture intersections. Because there is likely to be little mixing in the fractures, relatively high concentrations of contaminants can be transported long distances. DNAPL in fractures can migrate to significant depths and provide a deep source for mixing at fracture intersections. Locally, upward gradients in bedrock may transport the dissolved contaminants back to shallower depths.

Direction of contaminant flow in fractures is dependent on the piezometric head of the fractures, the orientation of the fractures, and the extent that they intersect fractures of other orientations. If fractures of several orientations intersect, the resulting contaminant pattern will approximate that of a porous homogeneous medium. However, if one or two fracture orientations dominate the bedrock, the resulting contaminant distribution will be elongated in the direction of the fractures.

At CRREL fracture flow is likely to be a significant pathway for contaminant transport as evidenced by the detection of contaminants in all of the bedrock wells. However, at all of the bedrock/overburden couplet locations at CRREL, except for the CECRL16/17 couplet, the concentration of contaminants in the bedrock wells is significantly less than the concentration in the corresponding overburden wells, indicating that contaminants are transported in the dissolved phase or that mixing occurs at fracture intersections. Both the presence of contaminants in the bedrock aquifer, and the downward gradients identified throughout most of the site, suggest that the contaminants are transported through bedrock fractures. On the west side of the Connecticut River, contaminants have not been detected in either the shallow or deep overburden aquifer, but have been detected in the bedrock aquifer, indicating that the primary transport mechanism on the west side of the river is flow through fractured bedrock.

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6.0 Risk Assessment

6.1 Human Health Risk Assessment

6.1.1 Introduction

The purpose of this human health risk assessment is to determine if contamination detected at CRREL is likely to present a threat to human health. An overview of the site relative to potential human health risks is presented below. In subsequent sections, we summarize site data, determine potential human receptors, and discuss exposure scenarios appropriate to the site.

Overview

CRREL is a 30-acre active research facility west of and adjacent to State Highway 10, and 1.5 miles north of the town of Hanover in Grafton County, New Hampshire (Figure 1-1). The site is rectangular in shape and contains two steep hills, one of which slopes down to the Connecticut River to the west of the property. A small drainage pond for stormwater detention is located at the southwest corner of the site.

The CRREL facility consists of seven major buildings and other smaller support structures, including pump houses for five production wells and a ground water treatment building for VOC removal (Figure 1-2). This system treats water from CRREL production wells by first pumping the water through a sand filtration system to remove metals and then distributing the water through two air strippers. The air effluent is treated through exposure to a carbon filtration unit. After passing through the system, the water is used for non-contact industrial cooling and then discharged to the Connecticut River. More information on the buildings and activities at CRREL can be found in Section 1.2.

The CRREL site is a secured property with chain link fences and security gates that are only open during normal working hours. A security guard is posted at one entrance. Employees may walk the property and may spend their lunch hours sitting on the lawn. Grounds workers are regularly engaged in landscaping activities and gardening. A child care center is located on the southeast end of the CRREL property for employees' children. The area where children play at the child care center is separated by a fence from the rest of the property but is close to other buildings and the lawn. Student housing for Dartmouth College is adjacent to the site on the north and south.

Field investigations occurred mainly on site. However, nearby off-site locations included the Connecticut River and, in earlier investigations, a monitoring well network and several residential wells located across the river from the CRREL site in Vermont, as well as the Hanover municipal standby well, used only during severe drought conditions. The main water supply for the Town of Hanover comes from

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three surface water reservoirs on a hillside on Grasse Road. This supply is located approximately 6,200 feet to the southeast and upgradient of the site.

Investigations prior to Phase I and Phase II were related to suspected TCE contamination, focusing on ground water, at the CRREL site, and also included sampling of surface water in the Connecticut River adjacent to the site, and on the west side of the river. These investigations were conducted by various state and federal agencies, as well as by CRREL personnel between November 1990 and June 1991; previous investigations are summarized in Section 1.2.3. The results of these preliminary investigations showed contamination in the ground water at the production wells and in the Ice Well. Ground water pumped from the on-site production wells is used only for non-contact industrial use.

TCE was found in ground water from the Peacock and Goodrich residential wells, located 800 to 1,000 feet from the CRREL boundary, across the Connecticut River in Vermont. In response to these findings, the Peacock residence was linked to the town of Norwich municipal well in September 1991. The Goodrich residence had a carbon filtration unit installed, and more recently was linked to the town of Norwich municipal well. An additional residential well on the Vermont side of the river, the Britton well, has also been found to be contaminated and has been shut down. The Britton residence was hooked up to Norwich Municipal Supply in July 1993. Additional wells in Vermont, which are farther away from the site, are monitored biannually, and have not exhibited any contamination.

TCE was found in the Phase I investigation of the surface water near the storm sewer outfall on the eastern side of the Connecticut River (1 detect occurring at outfall out of 3 samples taken upstream, at, and downstream of the outfall, with a maximum detect of 220 ug/L); there were no detects of TCE or other compounds in sediments. Since the time of the Phase I investigation, the CRREL facility redesigned the industrial water supply wells and storm water discharge system to the Connecticut River to include a VOC remediation system (described above). This change is evident in the results of the Phase II investigation, which showed no detects in surface water and one detect of TCE in sediments (0.27 mg/kg).

For the Phase I RI field investigation, 16 known or potential sources of contamination were identified as AOCs at CRREL. Most of these are USTs that contained either TCE, No. 2 fuel oil, or gasoline. The history of each AOC is summarized in Section 2.1 and Table 2-2. Other AOCs at CRREL include storage areas, ponds, suspected disposal areas, and a test well known as the Ice Well. The purpose of the Phase I RI was to provide data sufficient to prioritize AOCs, to define physical characteristics, and to assess the nature and extent of contamination at the AOCs. The Phase II RI performed by Arthur D. Little was required to address data gaps remaining from Phase I RI. Physical characteristics of the site were studied

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through a variety of geological investigations. Chemical characteristics of the site were defined by sampling sediment and surface water in the Connecticut River and the drainage pond, and surface soil, subsurface soil, and ground water. Contaminant migration through ground water was also explored via geologic survey. In the Phase II remedial investigation, SVOC and metals analyses were not done based on an Army review that indicated a lack of site sources for SVOCs and metals, and because previous data reportedly showed no exceedances of U.S. Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs) (EPA, 1993b) in ground water for SVOCs or for metals.

6.1.2 Hazard Identification

In this section, we describe the extent of contamination found at the potential exposure points at the CRREL site.

Surface Soils

The surface soils of AOCs 2, 9, 13, and 15, the child care center, and of the entire site, are potential exposure locations for surface soil contact pathways; the data from these locations are shown in Table 4-5. As may be seen in the raw data tables for the Phase II investigation presented in Appendix N, analyses of samples from AOCs 13 and 15 did not find any contaminants. In AOC 2, TPH was detected in one of a total of four samples at 20 ug/g. In AOC 9, TPH was detected in three of seven samples at concentrations ranging from 20 to 320 ug/g. In addition, two VOCs were detected: 1,1,1-trichloroethane was detected once in six samples taken at 0.75 ug/g, and TCE was detected once in six samples at an estimated concentration of 120 ug/g. Acetone was detected in several samples, but as discussed in Section 2.6, acetone has been determined to be a laboratory contaminant for surface soil analyses.

Surface Water and Sediments of the CRREL Pond

Two samples of surface water and two samples of sediment were taken from CRREL pond in the Phase II investigation (Tables 4-2 and 4-4). In the surface water, dichlorobenzene was detected once at a concentration of 3.2 ug/l. In the sediment, TCE was detected once at a concentration of 1.8 ug/g.

Surface Water and Sediments of the Connecticut River

In the surface water of the Connecticut River, the Phase II investigation did not detect any contaminants, although as discussed in Section 2.0, the Phase I investigation did detect TCE in Connecticut River water at the CRREL outfall. In the sediments, TCE was detected once at 0.27 ug/g in the Phase II investigation (Tables 4-1 and 4-3). The Phase I surface water and sediment data are not considered in this review because they are not representative of current site conditions because data was collected prior to operation of the ground water treatment system.

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Ground Water

Ground water sample analyses found that some VOCs, as well as TPH, were detected in a large number of the samples taken (Table 4-7). VOCs that were detected in greater than 5 percent of the samples taken included 2-butanone (MEK), chloroform, cis-1,2-dichloroethene, tetrachlorethene, toluene, and trichloroethene. Trichloroethene was detected in 81 of 93 samples, at concentrations ranging from 1 ug/L to 200,000 ug/L, with the highest concentration detected in CECRL09. Acetone and methylene chloride were detected in many of the samples, but are considered laboratory contaminants. TPH was detected in 24 of 68 samples at concentrations ranging from 100 ug/L to 770,000 ug/L, with the highest concentration found in CECRL06 (the Ice Well is not considered representative of local ground water conditions since the Ice Well fluids are encased and are not in contact with ground water).

6.1.3 Dose-Response Assessment

Dose-response relationships, which describe the potential toxicity of chemicals, are derived by EPA from published toxicity data. From these data, EPA develops several sets of toxicity values to provide quantitative estimates of the toxicity of chemicals and resultant toxic effects. For carcinogenic effects, cancer potency factors (CPFs) have been developed, while for noncarcinogenic effects, such as organ damage or reproductive effects, EPA has developed reference doses (RfDs).

Cancer potency factors (CPFs) are quantitative risk estimates that relate the lifetime probability of excess tumors to the lifetime average exposure dose of a substance. The CPF (also called the cancer slope factor) is estimated by the use of mathematical extrapolation models, most commonly the linearized multi-stage model, and is presented as the risk per mg/kg-day (i.e., mg dose carcinogen per kg body weight per day). When adequate human epidemiology data are available, the maximum likelihood estimates of model parameters are used to generate a CPF. When only animal data are available, the CPF is derived from the largest possible linear slope that is consistent with the data (within the upper 95 percent confidence limit). In other words, the true risk to humans, while not identifiable, is not likely to exceed the upper-bound estimate, and may be considerably lower. This model assumes that there is no toxicity threshold and that exposures to any concentration of a carcinogenic substance may ultimately cause some carcinogenic effect.

Known or suspected human carcinogens are classified by the Carcinogen Assessment Group and are assigned a Weight-of-Evidence classification for carcinogenicity. The EPA classification is based on an evaluation of the likelihood that the agent is a human carcinogen. The evidence is characterized separately for human and animal studies as follows:

- Group A: Human Carcinogen (sufficient evidence of carcinogenicity in humans)

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- Group B: Probable Human Carcinogen (B1—limited evidence of carcinogenicity in humans; B2—sufficient evidence of carcinogenicity in animals with inadequate or lack of evidence in humans)
- Group C: Possible Human Carcinogen (limited evidence of carcinogenicity in animals and inadequate or lack of human data)
- Group D: Not Classifiable as to Human Carcinogenicity (inadequate or no evidence)
- Group E: Evidence of Noncarcinogenicity for Humans (no evidence or carcinogenicity in adequate studies)

Carcinogenic potential may vary by route of exposure (e.g., oral and dermal); some contaminants are carcinogenic by one route, but not another.

For substances suspected to cause noncarcinogenic chronic health effects, the toxicity value is the RfD, expressed as chronic intake levels (in units of mg/kg-day) below which no adverse effects are expected. RfDs provide a benchmark for the daily dose of a chemical to which humans (including sensitive populations such as children) may be subjected without an appreciable risk of deleterious effects during a lifetime (assumed to be 70 years). In contrast with the underlying toxicological model used in the evaluation of carcinogenic risk, which assumes no threshold for carcinogenic effects, the noncarcinogenic effect model assumes a "threshold" concentration; exposures to concentrations below this threshold are not likely to cause adverse health effects.

The basis of an RfD derivation by the EPA is usually the highest dose level administered to laboratory animals that did not cause observable effects, the No Observed Adverse Effect Level (NOAEL), after chronic (usually lifetime) exposure. The NOAEL is then divided by an uncertainty (safety) factor, and sometimes an additional modifying factor, to account for extrapolations from animal data and to protect sensitive subpopulations. In general, an uncertainty factor of 10 is used to account for interspecies variation and another factor of 10 to account for sensitive human populations. Additional factors of 10 are included in the uncertainty factor if the RfD is based on the lowest observed adverse effect level (LOAEL) instead of NOAEL, or an experiment that includes a less than lifetime exposure.

6.1.4 Exposure Assessment

The objective of the exposure assessment is to evaluate the potential for human exposures to contaminants detected at the CRREL site. Potential exposure pathways are identified by evaluating current and future uses of the site. The current use of the

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site is an operating research facility. The site also contains a child care center for children of facility staff.

Potential human exposure pathways are summarized in Table 6-1 and are discussed below.

Complete exposure pathways must consist of four elements:

- A source and mechanism of release
- An environmental transport medium for the released chemical (pathway)
- A receptor and a point of potential contact with the contaminated medium
- A human exposure route at the point of contact

Potentially contaminated media at the CRREL site may include:

- Surface soil
- Subsurface soil
- Air
- Surface water of the Connecticut River
- Sediments of the Connecticut River
- Fish of the Connecticut River
- Surface water of CRREL pond
- Sediments of CRREL pond
- Ground water

Potential exposure routes may include:

- Incidental ingestion of soil
- Dermal contact with soil
- Inhalation of volatile compounds and/or particulates from soil
- Incidental ingestion and dermal contact with surface water and sediments of CRREL pond
- Incidental ingestion and dermal contact with surface water and sediments of the Connecticut River
- Ingestion of fish from the Connecticut River
- Ingestion of ground water
- Dermal contact with ground water
- Inhalation of volatile compounds from ground water

Potentially exposed populations may include:

- Facility staff/grounds workers
- Future construction workers

Table 6-1
Review of Potential Exposure Scenarios
CRRRL Site

Medium	Potential Exposure Pathways	Potentially Exposed Population	Potential Exposure Scenarios	Discussion of Applicability to Site
Surface soil	Incidental Ingestion	Facility staff	Staff sitting on grounds	For all potential exposures to surface soil: low frequency of detects, detected concentrations in surface soil are low, and outdoor exposures to surface soils would be infrequent.
	Dermal Contact	Grounds workers	Gardening activities	Exposures via volatilization and particulates from the surface are likely to be small.
	Inhalation of VOCs and particulates	Children	Outdoor play at child care center	
Subsurface soil	Incidental Ingestion	Construction workers	Future on-site construction	Risks related to future on-site construction would be evaluated under Army guidance prior to start of construction.
	Dermal Contact			
	Inhalation of VOCs and particulates			
	Inhalation of VOCs in on-site basements	Facility workers	Basement infiltration of volatiles	Depth to ground water is far below basements, and no workers in sub-basements
Drainage Pond	Incidental ingestion	Facility staff	Accidental fall into pond/pond maintenance	Exposures to pond surface water and sediments would be very infrequent, low frequency of detects, and detected concentrations are low.
	Dermal contact			
Connecticut River Surface Water Sediments	Incidental ingestion	Adults/older children	Recreational swimming	No detected chemicals in Phase II surface water data, low detected concentrations and frequency of detects in sediments, and frequency of contact is likely to be low.
	Dermal contact	Adults/children	Consumption of fish caught recreationally	No chemicals were detected in surface water in Phase II investigation; chemicals were detected in sediments at low levels.
	Fish Ingestion			
Ground Water	Ingestion	Adults	Future residential use	The most probable future use of the site is the current use; it is unlikely that ground water residential use wells would be installed on the site or in the area surrounding the site, based on existence of municipal supply.
	Dermal contact	Children		
	Inhalation of VOCs			
	Inhalation of VOCs in on-site basements	Facility workers	Basement infiltration of volatiles	Low detected concentration of VOCs in surface soil, depth to ground water is far below basements, and workers infrequently in sub-basements.

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- Children at the day care center
- Recreational users of the Connecticut River
- Future residential users of ground water

Potential exposure scenarios, and a discussion of their appropriateness based on site conditions and site uses at CRREL, are described below.

1. For facility grounds workers, exposure to surface soils across the entire site could occur during gardening or maintenance activities. Contact with surface soils for these workers is expected to occur only during the summer months. Only two VOCs were detected in surface soils, both at AOC 9 to evaluate soil conditions, 37 surface soil samples were taken throughout the site. Both 1,1,1-trichloroethane (detected at 0.75 ug/g) and TCE (detected at an estimated value of 120 ug/g) were detected only once in six samples taken at AOC9. The compound 1,1,1-trichloroethane has a published RfD of 9×10^{-2} mg/kg/day (EPA, 1993a) to evaluate potential noncancer risks. However, exposure to the low detected concentration of this compound in surface soil at one location is unlikely to pose a non-cancer risk, based on its published RfD and on the infrequent contact expected with surface soils at this single location. The single detected value for TCE in surface soils is an estimated value, which had been reported as "10 GT," where "GT" stands for "greater than." The accuracy of this estimated value cannot be determined, based on available data. Although EPA lists TCE as a B2 carcinogen, with a CSF of 1.1×10^{-2} (mg/kg/day)⁻¹ (sufficient evidence of carcinogenicity in animals with inadequate or lack of evidence in humans) (EPA, 1993a), this concentration of TCE is unlikely to pose significant carcinogenic risks based on the infrequent contact expected in surface soils at AOC 9. Another analyte detected in surface soil was TPH, however, no toxicity values exist for TPH (as a class). Detected TPH concentrations are discussed qualitatively in Section 6.1.5.
2. Potential exposure to subsurface soil would only occur for construction workers on the site in the future. Construction worker exposures to subsurface soils are not evaluated, because potential risks to construction workers are required to be considered, as described in the Army guidance "*Department of the Army Technical Manual 5-8XX-X Construction Site Environmental Survey and Clearance Procedures Manual*" (Draft). This manual establishes procedures for determining whether it is acceptable to construct at a particular site, based on site history and environmental surveys. Prior to any construction at a U.S. Army facility, the procedures described in the manual must be followed.
3. Children at the child care center could potentially be exposed to surface soils by incidental ingestion or dermal contact in the day care play area during outdoor play. Since only TPH was detected at the child care center at low concentrations,

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exposure of children to surface soils at the center are not quantitatively evaluated. The concentrations of TPH in surface soils are qualitatively discussed in Section 6.1.5.

4. Inhalation of VOCs and particulates is not quantified for on site populations. Inhalation of significant vapors originating from surface soils at depths of 0 to 2 feet is unlikely, because VOCs were rarely detected in surface soils, or were detected at low concentrations. Because VOCs must diffuse through the soil, potential air concentrations would likely be low. Additional dilution will occur as a result of turbulent mixing. As a result of these processes, air concentrations, even for a potential receptor located directly above the surface soils, are expected to be minimal. With regard to inhalation of particulates, the site is covered by grass, and therefore generation of airborne particulates from surface soil is only likely if the surface landscaping is cleared.

We do not quantify the potential inhalation exposure pathway resulting from infiltration of contaminants from soil or ground water into basements of buildings on the site. The exclusion of this exposure pathway is based on three factors: (1) there are low detected concentrations of VOCs in surface soil; (2) the depth to ground water at the site is 60 to 70 feet below the ground surface, thus the ground water level is far below the basements; and (3) workers are infrequently in the sub-basements on the site, since the sub-basement rooms are storerooms or are unused.

5. Accidental exposure to the surface water and sediments of CRREL pond could occur on a very infrequent basis. Because this scenario is highly unlikely, and would occur very infrequently, it is not quantified. In addition, the concentrations of contaminants detected in pond surface water and sediment are low, thus risks resulting from infrequent contact are not likely to be significant.
6. Individuals swimming in the Connecticut River could be exposed to surface water or sediments by incidental ingestion or by dermal contact. However, as discussed in Section 6.1.2, no contaminants were detected in surface water in Phase II sampling. In sediments, TCE was detected only once out of 15 samples, at a very low concentration (0.27 ug/g). This low concentration of TCE is not likely to pose significant risks, based also on the fact that swimming frequency in the area of the CRREL outfall is likely to be low. Because no contamination was detected in Connecticut River surface water and low concentrations were detected in only one sediment sample, fish are unlikely to take up significant concentrations of contaminants originating from the CRREL site. Therefore, the fish ingestion pathway is not quantitatively evaluated in this risk assessment.

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7. Future land use is expected to remain the same as the current use, as a research facility. Ground water pumped from the on site production wells is used only for non-contact industrial use, and likely future land use does not include development of ground water wells for residential use. All residences surrounding the site are connected to the Hanover municipal water supply. (In 1991, the CRREL facility publicly requested that all individuals with residential wells within a 2-mile radius notify the facility to receive free water testing. Later, the request was extended to include any resident with a well, regardless of distance from the site. All responses to this request were from the Vermont side of the Connecticut River. No residential use wells were located near the facility in New Hampshire.) The town water supply hook-up extends to at least 3 miles surrounding the CRREL facility. The Hanover standby well is used very infrequently; it has not been used at all for the past three years. This well is regularly monitored by the CRREL facility. The three private wells in Vermont that were found to be contaminated have been closed, and these residences have been hooked up to a municipal water supply. For the additional Vermont wells, biannual monitoring ensures that any future contamination would be detected in a timely manner. Therefore, risks related to residential use of ground water are not quantified.

In conclusion, the concentrations of contamination detected in media for which potential exposures are possible is so low that human health risks are unlikely. For other media, such as ground water, there are no complete exposure pathways. Therefore, the potential risks related to the CRREL site are qualitatively discussed in this human health risk assessment.

6.1.5 Risk Discussion

This section qualitatively discusses the potential risks to human health associated with each of the potential exposure media and exposure pathways at the CRREL site.

Surface Soil

As discussed in the previous section, the detected concentrations of contaminants in surface soil are unlikely to pose significant noncancer or cancer health risks to grounds workers at the facility. In addition, no toxicity values exist for TPH (as a class), therefore the detected TPH levels cannot be quantitatively evaluated. For comparison purposes, the state of Massachusetts has published a not-to-be-exceeded value for TPH in residential soils (500 ug/g) (MA DEP, 1993). The detected TPH concentrations in site soils fall below the 500 ug/g value (maximum concentrations range from 0.75 to 320 ug/g), thus exclusion of this class of compounds from the quantitative analysis of risks related to site soils is probably not significant. Of the two VOCs detected in surface soil, only TCE is a suspected carcinogen, however the single detected value for TCE is an estimated value. In addition, this concentration of

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TCE is unlikely to pose significant carcinogenic risks based on the infrequent contact expected for surface soils at AOC 9.

CRREL Pond

As previously discussed, contact with surface water or sediments of CRREL pond is not likely to occur, or would occur on a very infrequent basis. In addition, the concentrations of contaminants detected in the pond were low.

Connecticut River

In the Phase II sampling round, no contaminants were detected in Connecticut River surface water. No chemicals with noncancer health effects were detected in Connecticut River sediments. TCE was detected in sediments once in 15 samples, at a low concentration, which is not likely to pose significant risks.

Ground Water

No current exposure pathways and therefore risks are associated with the contaminated ground water beneath the CRREL site. Also, as previously discussed, residential exposure to ground water from beneath the CRREL facility is unlikely, because the site will remain a research facility in the future. In addition, all residences in the area of the facility are connected to a municipal water supply. Any new residences built in the area are likely to be connected to the Hanover municipal water supply.

6.1.6 Uncertainties and Limitations of the Risk Assessment

In this section, we discuss uncertainties and limitations associated with the data collection, toxicity assessment, and exposure assessment steps of this human health risk assessment. Although every human health risk evaluation involves some uncertainties and must, by necessity, use professional judgment, we have attempted to consider every possible exposure scenario. The uncertainties discussed would not be likely to change the conclusion that the risks associated with contamination at CRREL are minimal or nonexistent.

Data Collection

In the Phase II remedial investigation, SVOC and metals analyses were not done based on an Army review that indicated a lack of site sources for SVOCs and metals, and because previous data reportedly showed no exceedances of U.S. Environmental Protection Agency (EPA) Maximum Contaminant Levels (MCLs) (EPA, 1993b) in ground water for SVOCs or for metals. Although it was previously determined that metals and SVOCs are not associated with past site activities, and are not likely to be of concern at this site, the exclusion of these analytes from this risk assessment introduces some uncertainty into the overall risk discussion. However, because these analytes were previously determined not to be of concern, their exclusion is unlikely to affect the conclusions of the risk assessment.

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Finally, although an attempt was made to adequately sample all site media, the selection of sampling locations may not have been truly representative of site conditions. However, because we implemented a biased sampling strategy to detect contaminants in the most contaminated areas, the data represents a conservative estimate of risk.

Toxicity Assessment

The lack of toxicity values for each chemical detected introduces uncertainty into the risk assessment. If these chemicals actually cause adverse health effects, this lack of data would result in an underestimation of potential site risks. There is also uncertainty in assessing the toxicity of a mixture of chemicals. The approach used does not take into account interactions between chemicals in a mixture, which may result in effects greater or less than expected. However, because contaminants at CRREL were detected at low concentrations or because there is not a complete exposure pathway, the lack of toxicity values is unlikely to change the conclusions of the risk assessment.

Exposure Assessment

Based on the findings of contaminated subsurface soil and ground water, basement infiltration could be an exposure pathway, although, as previously discussed, few workers are actually using sub-basement areas of buildings on site. Since exposures are not calculated for inhalation of volatile compounds in basements of buildings on the CRREL site, the lack of quantification of these pathways may underestimate exposures and risks related to ground water and soil contamination.

In addition, exposures to subsurface soils could occur in the future if the ground cover is disturbed, or if there is digging at the site, although the possibility of subsurface exposure to construction workers would be addressed in compliance with the Army guidance "Department of the Army Technical Manual 5-8XX-X *Construction Site Environmental Survey and Clearance Procedures Manual*" (Draft), as previously discussed.

The use of professional judgment in determining exposure assumptions for potential exposure scenarios at CRREL introduces some uncertainty into the risk assessment. For example, we have assumed that exposure duration and frequency are likely to be low for grounds workers exposed to surface soils at the site, and for recreational swimming near the CRREL outfall. Because concentrations detected in surface soils and sediments are low, however, the risks associated with these pathways are likely to be low.

6.1.7 Summary of the Human Health Risk Assessment

Contamination concentrations for most media at the CRREL site, with the exception of ground water, are low and are unlikely to pose human health risks currently or in

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the future. Although ground water contamination was found, the future use of the site is likely to remain the same, making residential exposure to ground water from beneath the site an unlikely exposure scenario. The existence and availability of the Hanover municipal water supply system (which is physically and geologically unrelated to the CRREL site) in the area of the CRREL facility further supports the conclusion that no complete exposure pathways exist, or will exist in the future, for ground water from beneath the site. It should be noted that the CRREL facility is planning to continue with the removal of VOCs from site ground water, and that continued frequent monitoring of the Hanover municipal standby well and the Vermont residential wells should sufficiently protect users of these wells in the future.

6.2 Ecological Impact and Risk Assessment

6.2.1 Introduction

This ecological impact and risk assessment was performed to document any visible impacts of the CRREL facility on local ecological resources, and to identify potential risks of adverse ecological impacts from site-derived contaminants in soil, sediments, and surface waters to on-site and adjacent, off-site habitats. The technical approach for this impact assessment conforms to that outlined in Arthur D. Little's *Final Work Plan, Phase II Remedial Investigation for Cold Regions Research and Engineering Laboratory (CRREL), Hanover, NH*, Revision 1, dated July 9, 1993.

6.2.2 Overview of Technical Approach

A brief summary of the technical approach used in this assessment is presented below.

6.2.2.1 Ecological Research. The background ecological research effort during this study included a review of the National Wetlands Inventory (NWI) map for the site (Hanover, NH-VT USGS Quadrangle, 1990); and correspondence with the New Hampshire Natural Heritage Inventory Program. Occasional sightings of wildlife on the grounds of the CRREL facility by Arthur D. Little field staff also contributed to the ecological overview provided below.

6.2.2.2 Field Ecological Survey. A one-day site visit was conducted by Arthur D. Little's ecologist on August 10, 1993, to identify major habitat types, their dominant plant species, and any sensitive ecological receptors on site and in the immediately adjacent, off-site areas surrounding the CRREL facility.

6.2.2.3 Contaminant Evaluation. As part of the contaminant evaluation task for the ecological impact assessment, the following activities were conducted:

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- A statistical analysis of surface soil, sediment, and surface water contamination data for selected ecological exposure zones
- Ecotoxicological research on contaminants of concern (COC), by reviewing federal and New Hampshire ambient water quality criteria (AWQC), National Oceanic and Atmospheric Administration (NOAA) sediment quality guidelines, ecologically protective contaminant levels (PCLs) for upland soils, and other published ecotoxicological data for selected faunal species

The data sources used and results of this evaluation are presented in Section 6.2.4.4.

6.2.2.4 Assessment of Ecological Impacts and Risks. To qualitatively assess existing impacts and potential risks to ecological receptors from exposure to site-derived contaminants, the following activities were conducted:

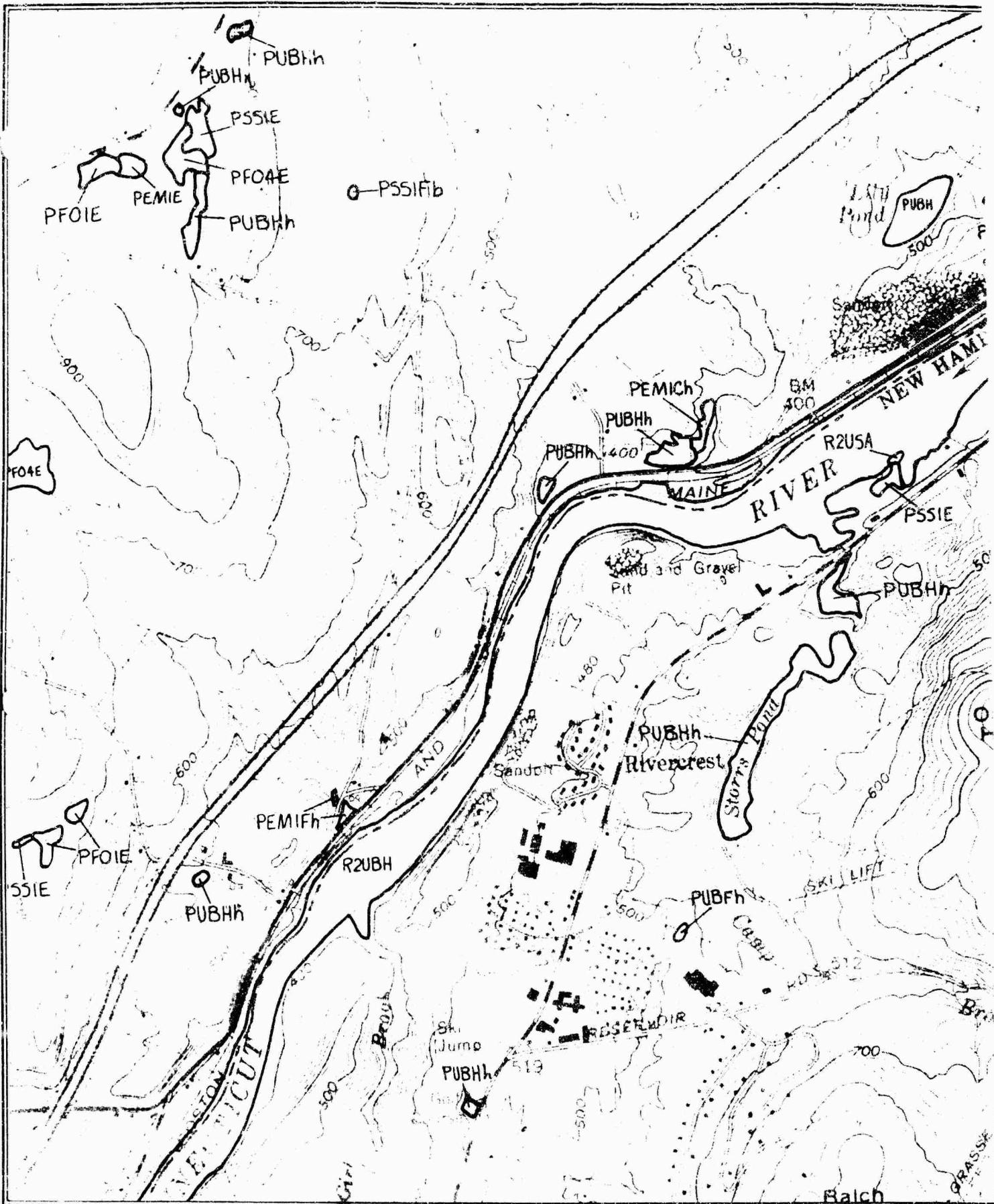
- An inventory and visual assessment of the types, apparent health, and integrity of all major habitats in each on-site or off-site ecological exposure zone
- An ecotoxicity assessment using freshwater AWQC, NOAA sediment guidelines, terrestrial soil PCLs, and other available, COC-specific ecotoxicological data
- A qualitative impact and risk assessment for these habitats, based in part on the calculation of COC-specific hazard quotients (HQs) and aggregate hazard indices (HIs) for their resident biotic communities

HQs and HIs are calculated by dividing the average and maximum COC concentrations in soil, sediment, and surface water of each exposure zone by their corresponding toxicity threshold concentrations, such as NOAA sediment guidelines, and New Hampshire freshwater AWQC. HQs or HIs in excess of 1.0 are considered to represent a potential ecological risk, respectively, for individual COCs or mixtures of COCs. HQs and HIs between 1 and 10 often are considered as "low potential risks," and those above 100 may indicate "high potential risks."

Since this is a screening-level ecological impact and risk assessment, no modeling of indirect, food chain exposure risks to individual indicator species is performed. For small mammals found on site, such as rabbits, however, a few estimates of worst-case exposures from ingestion of terrestrial soil contaminants are made to provide some context for qualitative risk considerations.

6.2.3 Biota and Ecosystems Inventory

6.2.3.1 Overview of Study Area Ecosystems. Figure 6-1 is a site locus map. Figure 6-2 (plate) is a detailed site plan showing the site's topography, locations of



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SOURCE: NATIONAL WETLANDS
INVENTORY MAP
HANOVER NH-VT, 1990
(FROM 1985 AERIAL SURVEY)

TITLE:
**FIGURE 6-1
NWI LOCUS MAP FOR
THE CRREL SITE,
HANOVER, NH**

Arthur D Little

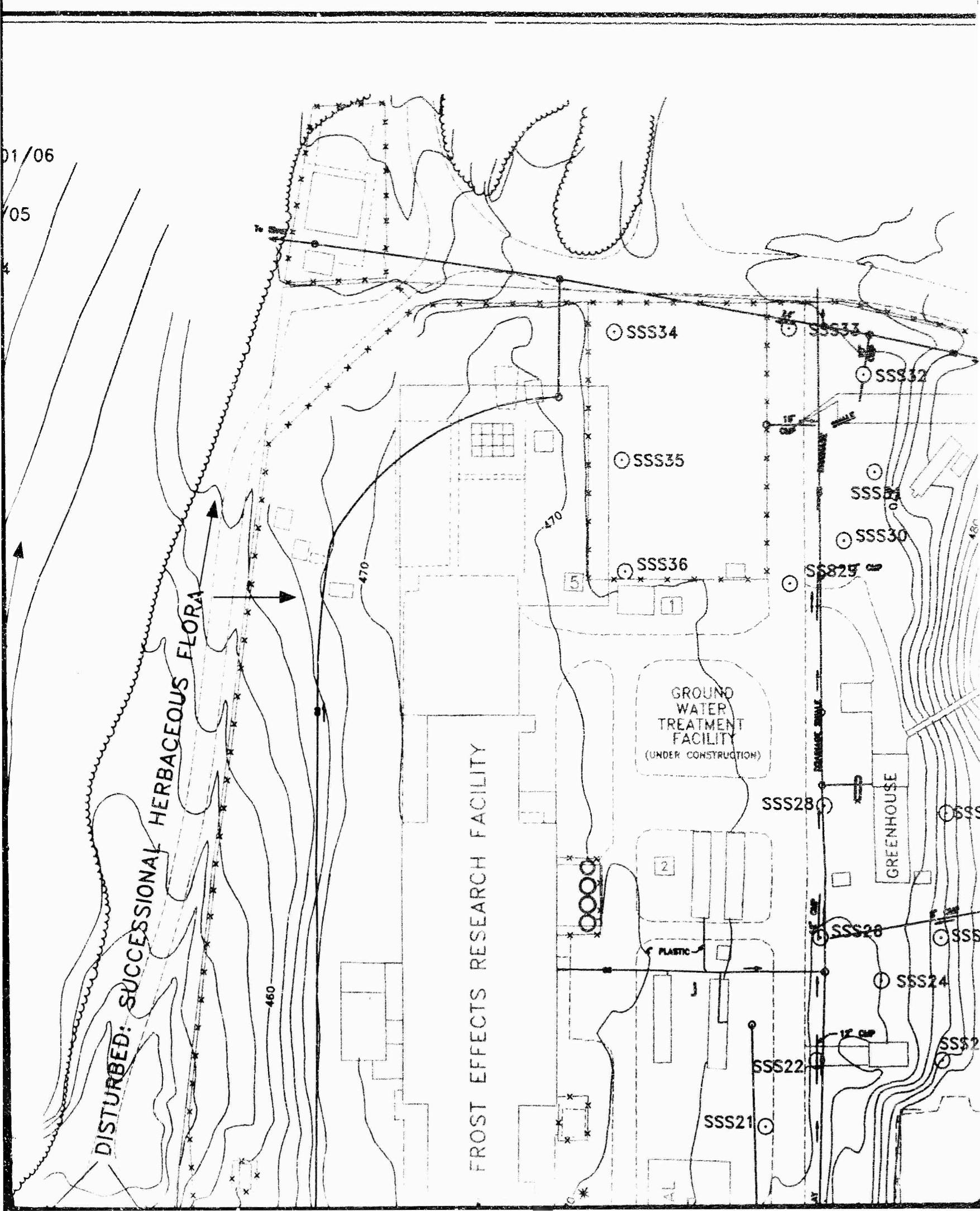
CONNECTICUT RIVER

CONN14
CONN15
CONN11
CONN13
CONN10
CONN12
CONN03/04
CONN02/05
CONN01/06

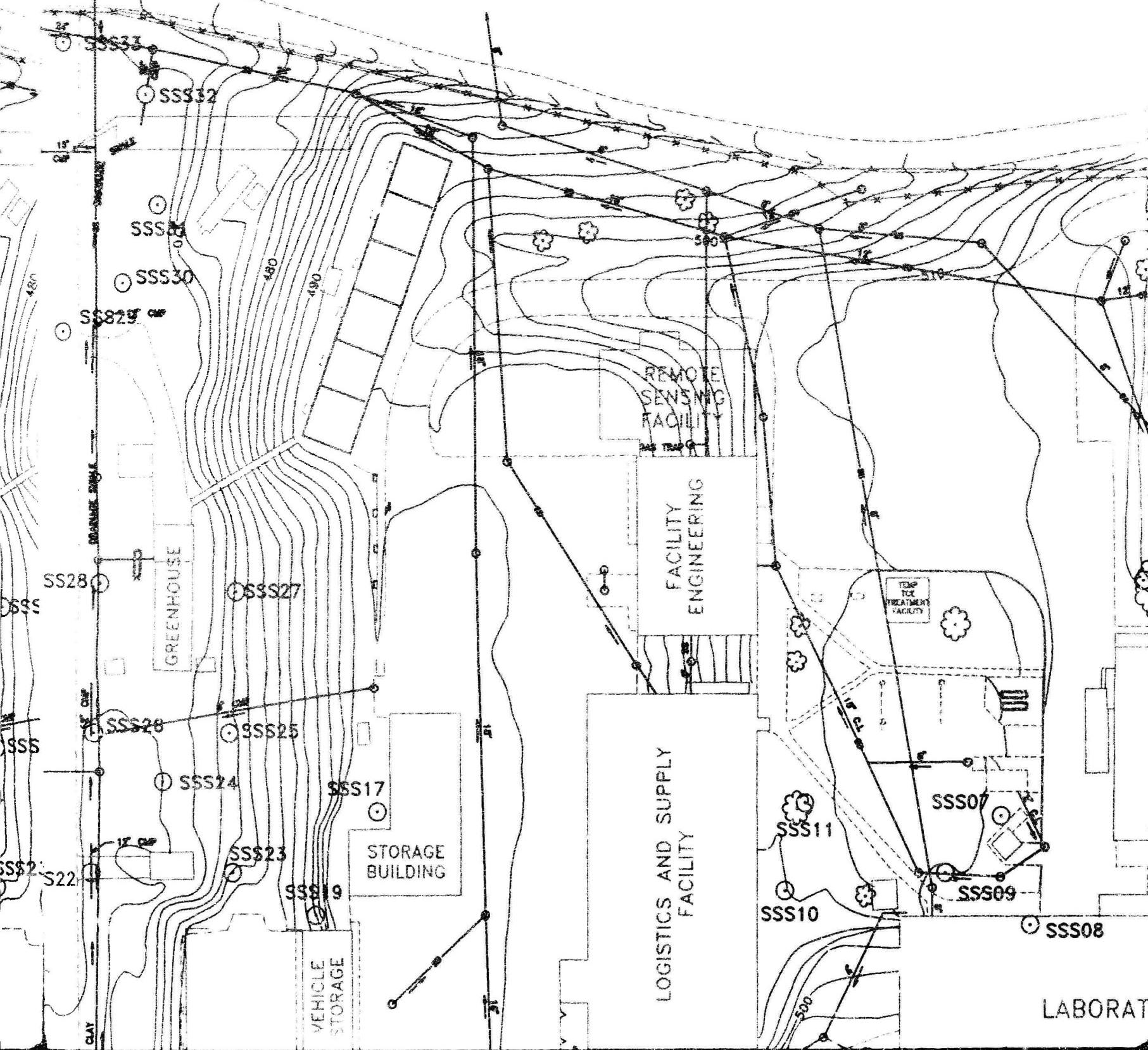
400
420
440
460
MIXED DECIDUOUS FOREST

DISTURBED: SUCCESSIONAL HERBACEOUS FLORA

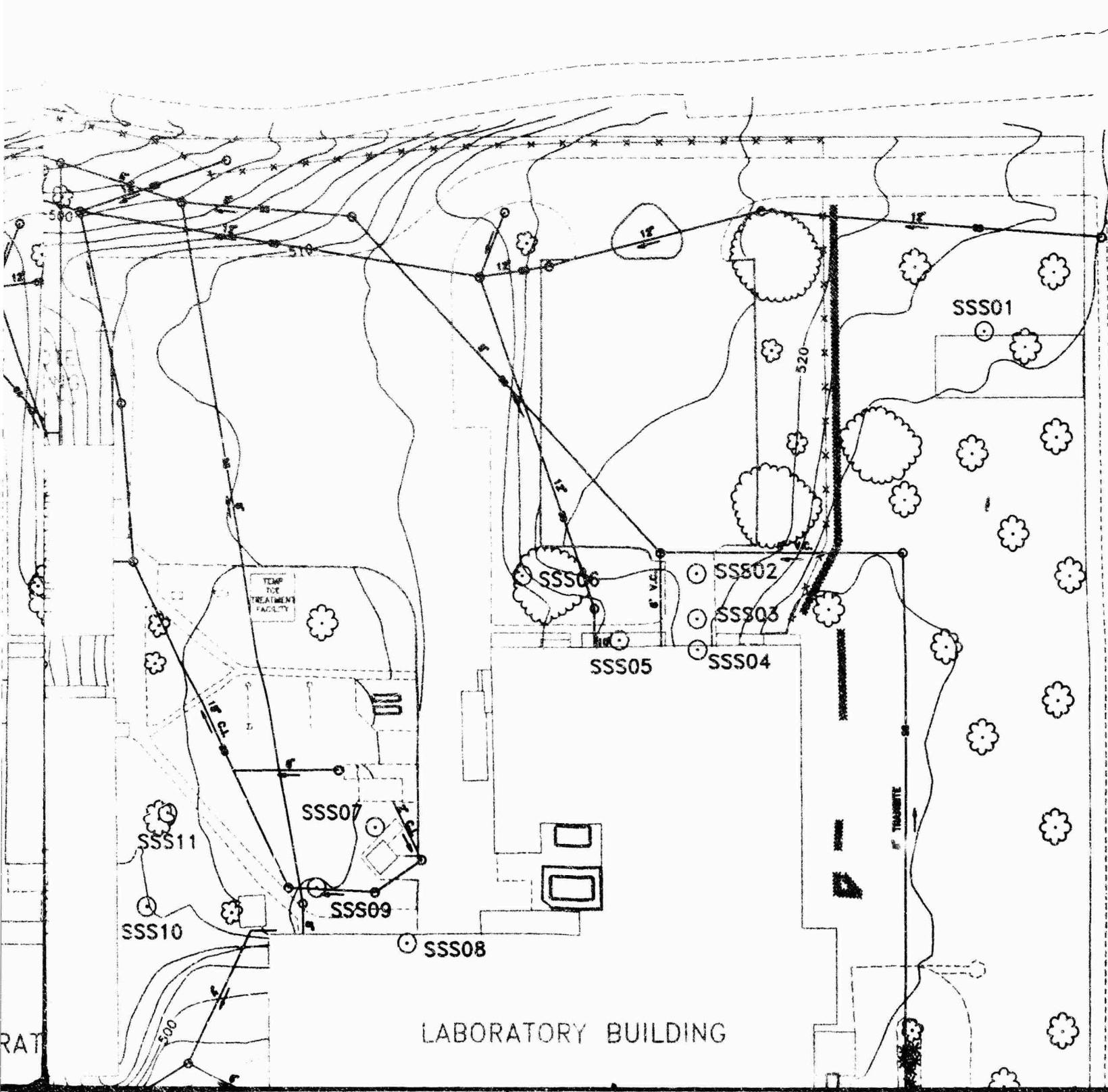




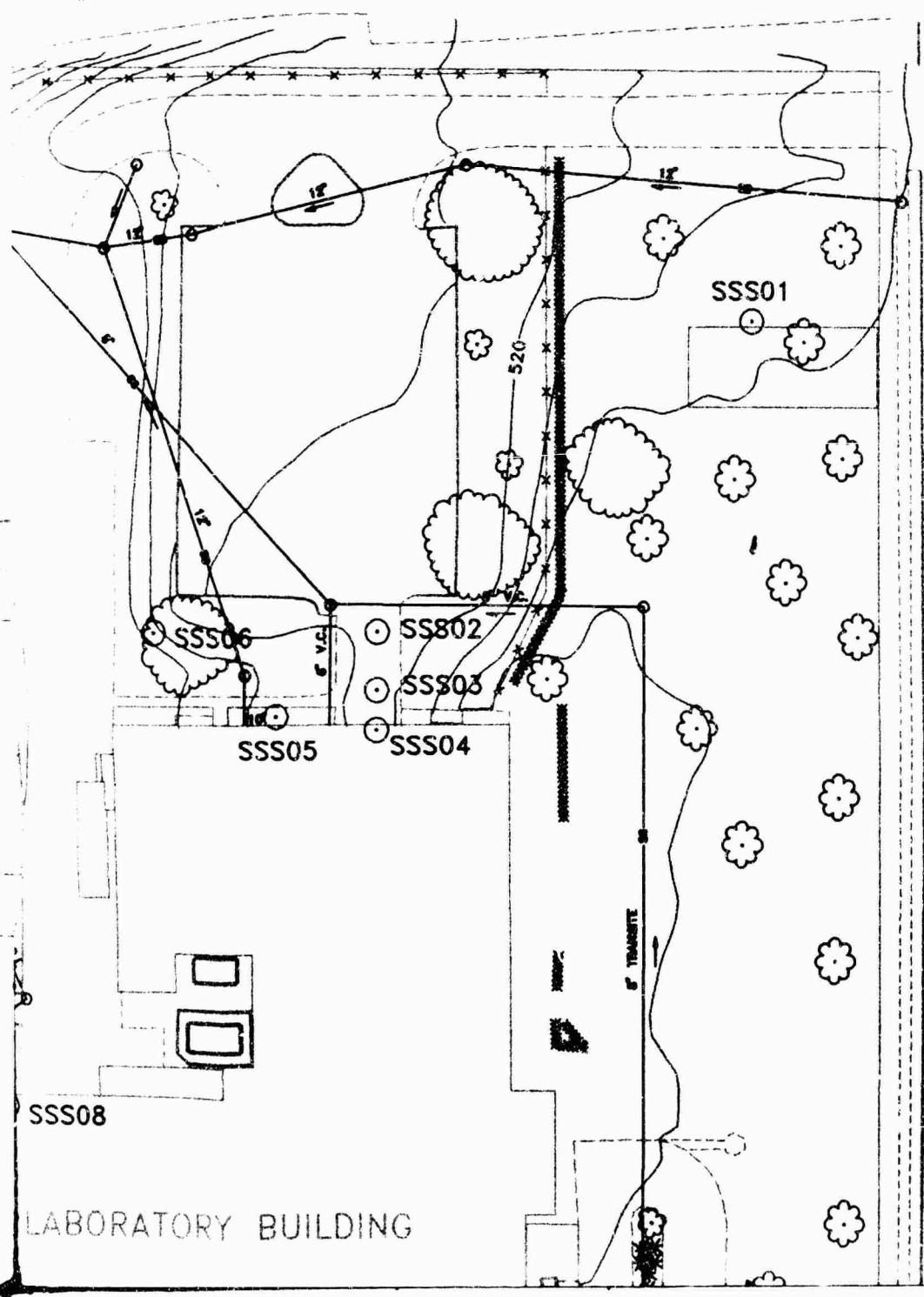
LANDSCAPED RESIDENTIAL AREA



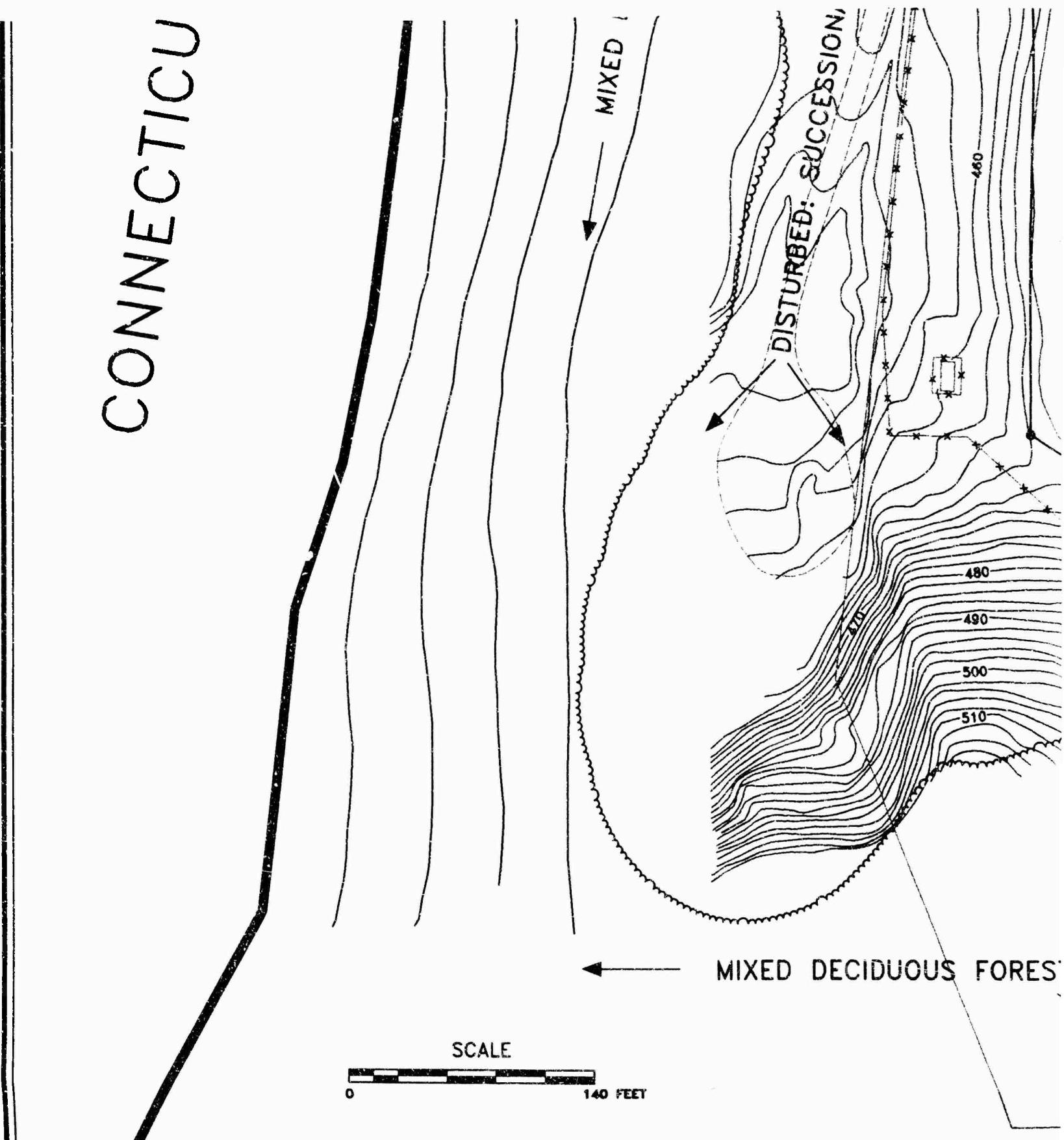
DISCAPED RESIDENTIAL AREA →



EA →



CONNECTICU



PREPARED FOR:

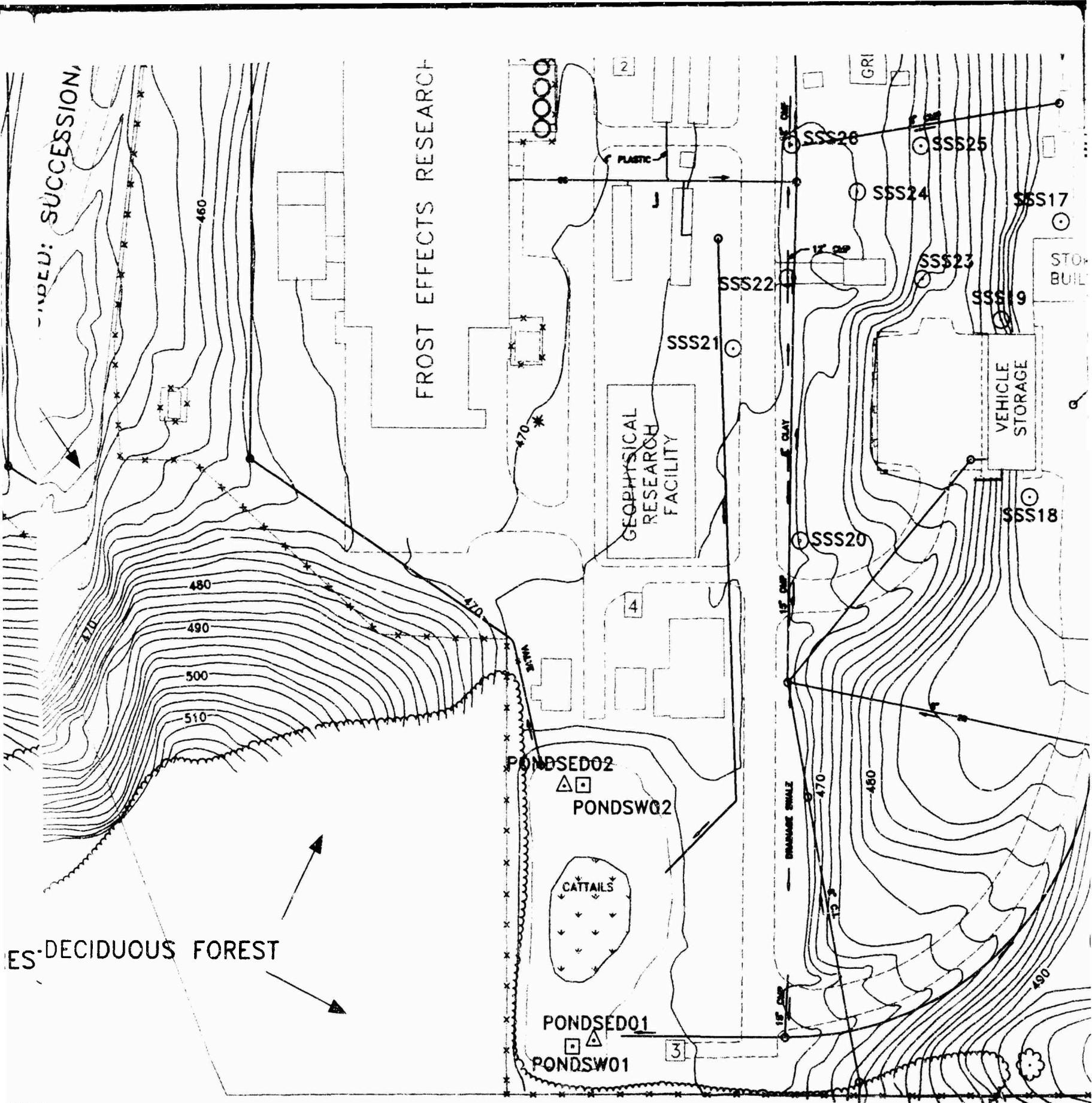
USAEC

DATE:

JAN., 1994

SCALE:

1" = 70'



ES-DECIDUOUS FOREST

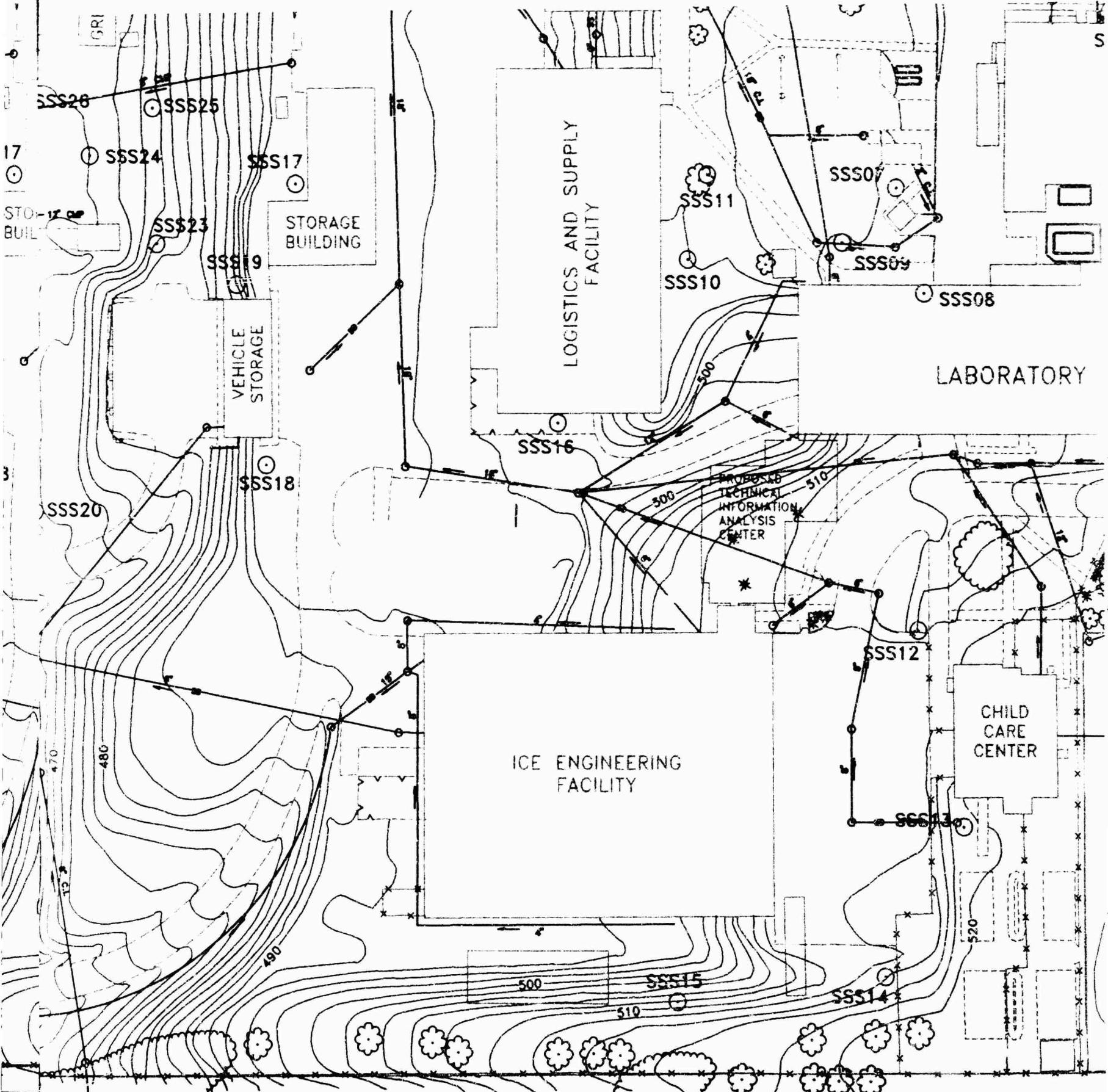
FROST EFFECTS RESEARCH

DWG. NO.

67063-029

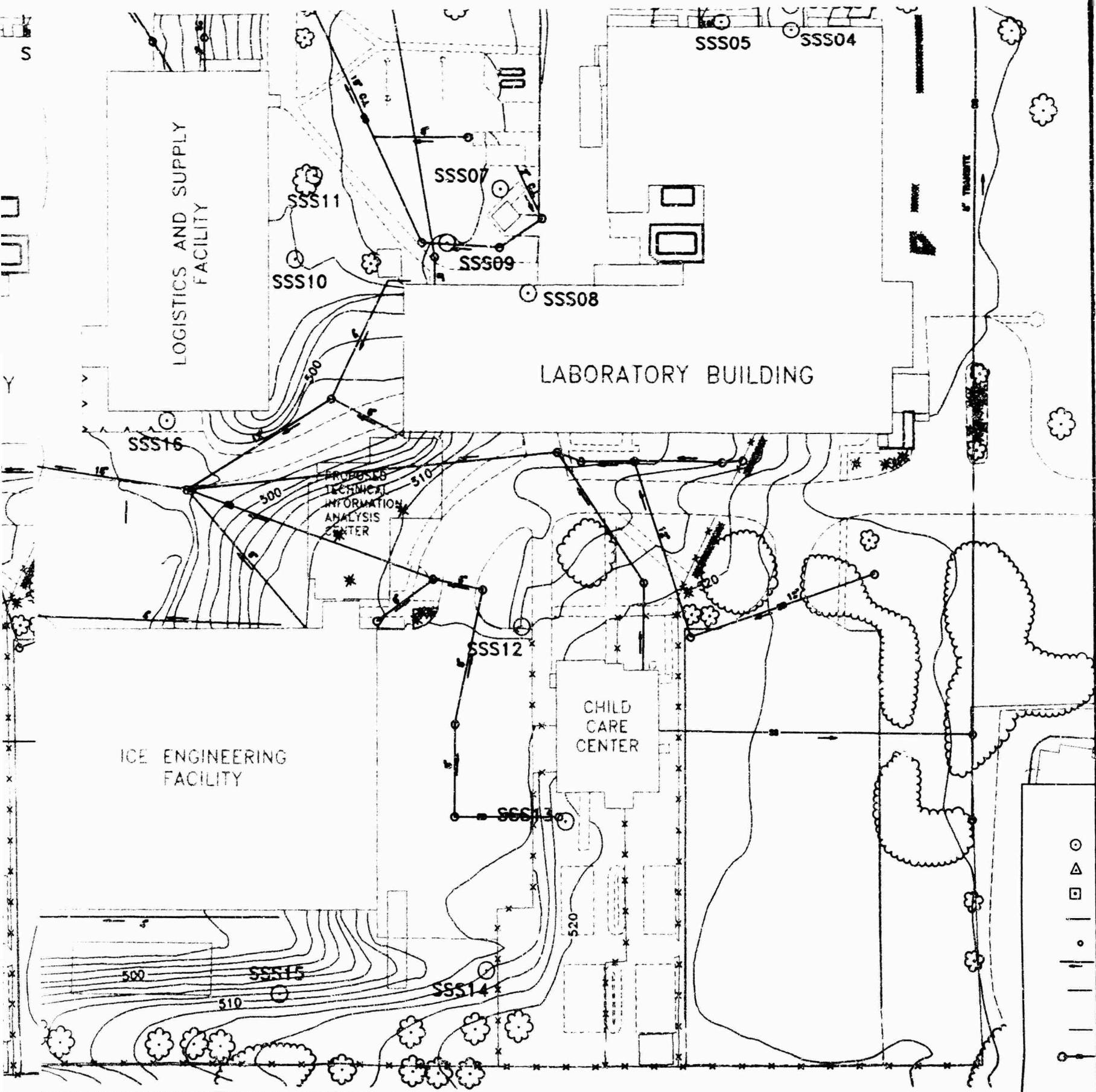
DRAWN

APPROVE



WN	DRAWN BY: (INITIALS) MSB/LBM/THC
ROVE	APPROVED BY: (INITIALS)

Arthur D Little

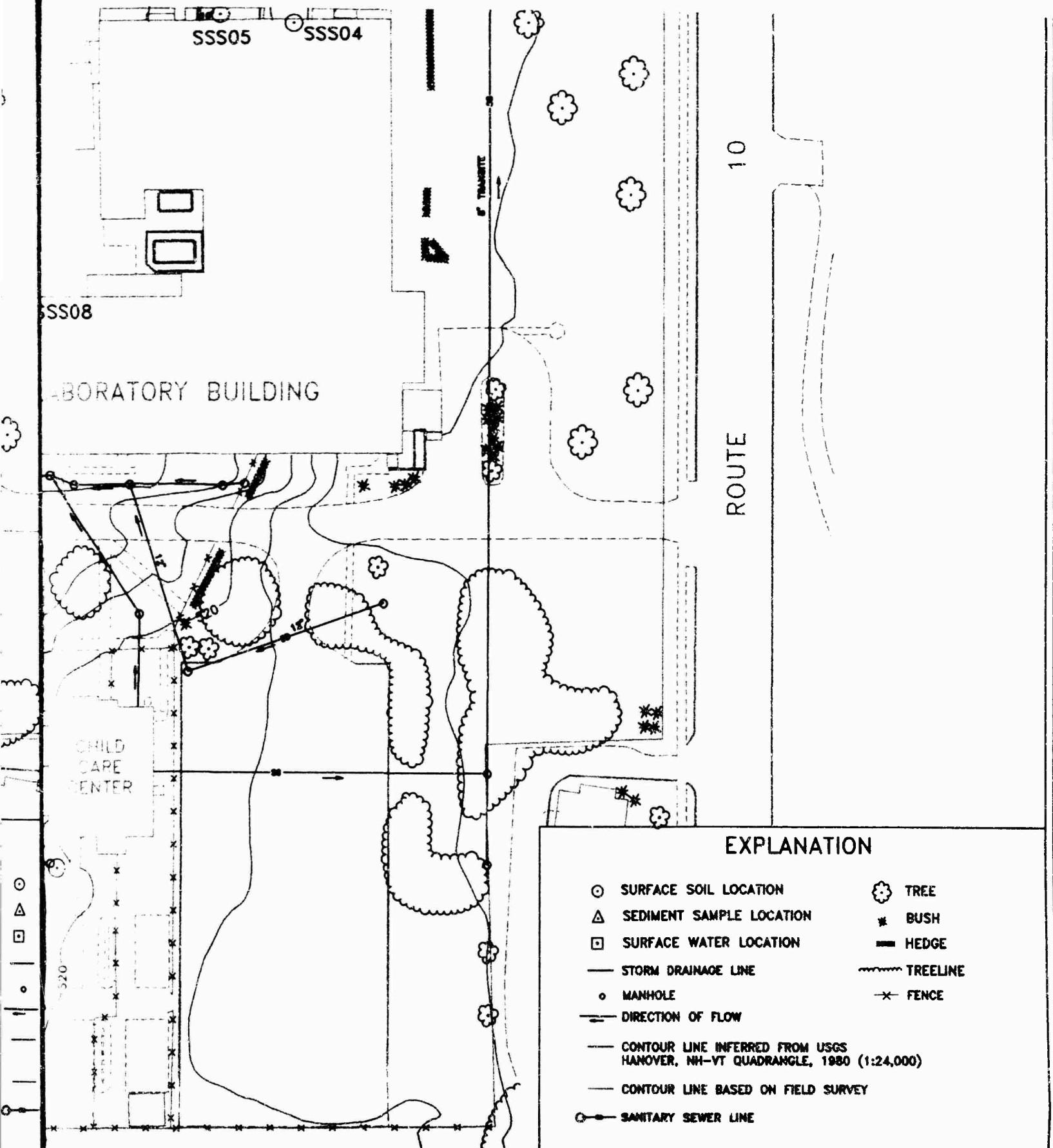


/THC
ALS)

Arthur D Little

TITLE:

FIGURE 6
COLD REGIONS RESEARCH
ENGINEERING LABORATORY
MAP OF SITE TOPOGRAPHY
AND SAMPLING



RE 6
S RES
G LA
OGR
NG

TITLE:

FIGURE 6-2
COLD REGIONS RESEARCH AND
ENGINEERING LABORATORY
MAP OF SITE TOPOGRAPHY, HABITATS,
AND SAMPLING LOCATIONS

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dominant plant communities within and immediately adjacent to the CRREL property, and the soil, sediment, and surface water sampling locations. Brief descriptions of major habitats are presented below for on-site and off-site ecological exposure zones.

6.2.3.1 On-Site Habitats. As reflected in the following descriptions, the CRREL property contains very little terrestrial, wetland, or aquatic wildlife habitat, due to its extensively developed nature.

On-Site Terrestrial Habitats: Upland vegetative cover consists entirely of maintained lawns and foundation plantings around the buildings, such as small flower gardens, and both deciduous and evergreen shrubs and trees.

On-Site Wetland Habitats: No on-site wetland resources appear in the NWI map, presented in Figure 6-1. Rather, the NWI map shows only a broad drainage swale formed by the 460-foot elevational contour, across which an earthen berm was built during the 1980s to create the stormwater detention pond located in the southwest corner of the property. A small palustrine wetland, however, has since become established within this pond (see Figures 6-2 and 6-3A). Based on its hydrology, soils, and emergent wetland vegetation such as cattails (*Typha latifolia*), this vegetated detention pond area may qualify as "waters of the United States" under Section 404 of the Clean Water Act (33 USC 1344).

Controlled discharges of stormwater and process water are periodically pumped from the northwest corner of this pond/wetland through a closed-pipe system and discharged into the Connecticut River. This pond, however, is a low quality wetland unlikely to provide significant food or habitat resources for wildlife, for three reasons:

- It is isolated from the water table by a clay liner and is seasonally dry
- It is routinely used to detain stormwater and has previously been used for detention of urea/water solutions
- It is used as a disposal area for soils and lawn trimmings

On-Site Aquatic Habitats: No perennially flooded surface water bodies or waterways occur on the CRREL property. Since the cattail-dominated stormwater detention pond described above dries up seasonally, it is not considered a true aquatic habitat. Intermittently flowing drainage ditches on the CRREL site also are not considered as aquatic habitats within which fauna are likely to be exposed to site-derived sediment or surface water contaminants.

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Figure 6-3A: Southern aspect of eastern edge of the detention pond/wetland, showing fresh soil deposits (at left) and Cattails in center.



Figure 6-3B: Western aspect of a disturbed, off-site area with successional herbaceous flora (foreground) and the top of the steep, forested slopes located above the Connecticut River (background).

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On-Site Ecological Receptors: On-site ecological receptors potentially exposed to site-derived contamination might include the following:

- Terrestrial and wetland plant species found on site, and any herbivorous fauna feeding on these plants
- Terrestrial soil invertebrates, and carnivorous species of birds and small mammals that feed on these soil organisms
- Benthic and pelagic invertebrates inhabiting, respectively, the sediments and surface water column of the stormwater detention pond/wetland
- Any resident amphibians, birds, migratory waterfowl, or mammals that may use or feed in this pond/wetland

For the purposes of this impact and risk evaluation we assume that these categories of fauna inhabit and/or visit the CRREL site, although no survey of soil or sediment-dwelling invertebrates was conducted. Fauna residing in off-site receptor habitats are also acknowledged as potential on-site receptors, since those bird and mammal species that forage widely may visit the CRREL property on occasion.

6.2.3.3 Off-Site Habitats and Receptors. Off-site habitats and ecological receptors occurring immediately adjacent to the CRREL property include:

- Residential areas of lawn, gardens, and other landscape plantings, located north, east, and south of the CRREL property
- Open fields with successional herbaceous vegetation, in adjacent, disturbed areas such as the sandy fill extraction pits between the site and the Connecticut River (see Figure 6-3B)
- Small areas of mixed, hardwood-dominated forest, mostly south and southwest of the property, with a narrow band of forest on the steep slopes located between the site and the east bank of the Connecticut River
- Freshwater aquatic habitats of the Connecticut River, located west of the site

A brief description of each of these adjacent, off-site habitats is provided below. Approximate locations of these off-site lawn, successional field, and mixed forest habitats are shown in the CRREL site plan (Figure 6-2).

Off-Site Terrestrial Habitats: Landscaped residential areas are the dominant habitat type located on three sides of the CRREL property. Undeveloped, upland habitats include recently cleared/excavated areas that are now dominated by an early successional flora consisting mostly of grasses (*Poaceae*) and herbaceous species of

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weedy plant families such as the Asteraceae, including Ragweed (*Ambrosia* spp.) and Goldenrod (*Solidago* spp.).

Young forest habitats are confined mostly to areas between the site and the Connecticut River. Although it is best classified as a Canadian Hemlock/Northern Hardwood forest, the Canadian Hemlocks (*Tsuga canadensis*) of this riverside forest are a minority element of the canopy in those areas immediately adjacent to the CRREL site. Dominant tree and shrub species of this young riverside forest are listed in Table 6-2.

Despite their immature stature, these forest areas and the successional flora of the adjacent fields offer the best wildlife food and cover resources found adjacent to the CRREL property and Connecticut River.

Off-Site Wetland Habitats: As shown in the NWI locus map (Figure 6-1), vegetated wetland habitats do not occur locally in adjacent, off-site areas along the Connecticut River. Although some wetland plant species might occur along the intermittent stream emanating from the southwest corner of the CRREL site, such areas are not considered as true wetlands, or "waters of the United States," as defined in Section 404 of the Clean Water Act (33 USC 1344). This lack of off-site wetlands was verified during the site visit by Arthur D. Little's wetland ecologist.

Off-Site Aquatic Habitats: The only true aquatic habitat located adjacent to the site is the Connecticut River, which flows southwards and lacks emergent aquatic vegetation in areas adjacent to the site. The benthic habitat of the river along this segment consists mostly of a sandy bottom near the shoreline, with a gravel/cobble bottom, reportedly inhabited by freshwater mussels, in the deeper, mid-channel area.

A south-draining, grassy swale also occurs within the mixed forest located along the Connecticut River southwest of the site. This swale carries intermittent surface water runoff into a perennial, feeder stream of the Connecticut River known as Girl Brook, presumably only after significant rainfall events (Figure 6-1). Due to its intermittent hydroperiod and the terrestrial flora within its upper reaches near the stormwater pond in the southwest corner of the site, however, this tributary of Girl Brook cannot be classified as an aquatic habitat.

Off-Site Ecological Receptors: For the purposes of this ecological impact and risk assessment, any visits to the CRREL property by faunal species residing in off-site habitats, such as migratory species of songbirds or waterfowl, will be considered within the context of *on-site* exposure scenarios to soil, sediment, and/or surface water contaminants. At present, therefore, the only *off-site* ecological receptors of site-derived contamination are the aquatic habitats and biota of the Connecticut River, since contaminants are released from the CRREL facility as a result of normal,

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Table 6-2: Dominant Flora of the Canadian Hemlock/Northern Hardwood Forest between the CRREL Site and the Connecticut River

Species Name	Common Name
*Trees:	
<i>Acer pennsylvanicum</i>	Striped Maple
<i>Acer rubrum</i>	Red Maple
<i>Acer saccharum</i>	Sugar Maple
<i>Betula allegheniensis</i>	Yellow Birch
<i>Betula lenta</i>	Sweet Birch
<i>Betula populifolia</i>	Grey Birch
<i>Fraxinus americana</i>	White Ash
<i>Pinus strobus</i>	White Pine
<i>Populus grandidentata</i>	Big-tooth Aspen
<i>Populus tremuloides</i>	Trembling Aspen
<i>Quercus rubra</i>	Northern Red Oak
<i>Robinia pseudoacacia</i>	Black Locust
<i>Tilia americana</i>	American Basswood
<i>Tsuga canadensis</i>	Canadian Hemlock
Shrubs and Vines:	
<i>Apocynum cannabinum</i>	Indian Hemp
<i>Cornus alternifolia</i>	Alternate-leaved Dogwood
<i>Corylus</i> sp.	Hazelnut
<i>Lonicera</i> sp.	Honeysuckle
<i>Rhamnus</i> sp.	Buckthorn
<i>Rhus radicans</i>	Poison Ivy
<i>Rhus typhina</i>	Staghorn Sumac
<i>Taxus</i> sp.	Yew
Herbs:	
<i>Aralia nudicaulis</i>	Sarsparilla
<i>Ambrosia artemesiiifolia</i>	Ragweed
<i>Aster</i> spp.	Asters
<i>Dryopteris</i> spp.	Wood Ferns
<i>Equisetum</i> sp.	Horsetail
<i>Oenothera biennis</i>	Primrose
<i>Onoclea sensibilis</i>	Sensitive Fern
<i>Polygonatum biflorum</i>	Solomon's Seal
<i>Rudbeckia hirta</i>	Black-eyed Susan
<i>Solidago</i> spp.	Goldenrod

*Note: tree list includes canopy and understory elements.

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NPDES-permitted operational discharges of combined process wastewater and stormwater into the river.

Historically, however, another off-site ecological receptor of contaminants in surface water runoff was an area of mixed forest and associated drainage swales, located on abutting properties between the southwest corner of the site and the Connecticut River. Aerial photographs from 1970 and 1974 show that surface runoff from the site traversed this area prior to the construction of the stormwater detention pond during the 1980s (EPA, 1991). A 1982 aerial site photograph in this same EPA site analysis report shows at least the beginnings of the pond's southern berm, which is now the surface water divide for the western part of the site. Since the berm was built at least four years after the 1970 release of TCE into the Connecticut River, the off-site area of mixed forest and/or its grassy swale also may have received contaminated surface water runoff from the CRREL site. This berm apparently lacks a discharge pipe, so that all of the effluent now leaves the northwest corner of this detention pond through the subsurface process and stormwater drainage system, which discharges directly to the Connecticut River.

6.2.3.4 Faunal Diversity of the Connecticut River Basin. Based on a review of regional ecological literature, in its 1993 *Draft Ecological Risk Assessment for the BFI Landfill in Rockingham, Vermont*, Balsam Environmental Consultants (BEC, 1993) estimated that the Canadian Hemlock/Northern Hardwood forests, floodplain wetlands, and aquatic habitats associated with the Connecticut River between Rockingham and Vernon, Vermont, may support as many as 170 different species representing 138 genera of amphibians, fish, reptiles, birds, and mammals, including the following:

- 26 genera and 38 species of fish
- 24 genera and 31 species of amphibians and reptiles
- 56 genera and 64 species of birds
- 32 genera and 37 species of mammals

In addition, BEC (1993) cited an inventory of aquatic invertebrate communities from the Connecticut River in Vernon, Vermont (Aquatec, 1990, 1992) which includes:

- 90 species representing 81 genera of benthic invertebrates
- 28 species representing 22 genera of pelagic zooplankton

Based on these limited biogeographical data, the habitats and vegetative communities associated with the Connecticut River and its tributaries are capable of supporting a significant diversity of faunal species and communities.

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6.2.3.5 Faunal Populations in the CRREL Study Area. No surveys of the terrestrial, wetland, and aquatic fauna on and around the CRREL site were conducted to identify the dominant vertebrate and invertebrate fauna of the past and present ecological receptor habitats. However, it seems unlikely that the faunal species diversity of the CRREL study area would equal that reported for the Vernon or Rockingham, Vermont areas, due to the more developed conditions of the CRREL site and its environs, as compared to these other river segments. Freshwater mussels attached to the gravel/cobble substrate of the mid-channel portion of the Connecticut River were the only aquatic species sighted by the Arthur D. Little team during the Phase II sampling of river sediments and surface water.

Visual evidence of on-site mammal populations includes many incidental sightings by Arthur D. Little's field personnel of species that are tolerant of human activity, such as Eastern Cottontail Rabbits (*Sylvilagus floridanus*), Woodchucks (*Marmota monax*), Grey Squirrels (*Sciurus carolinensis*), Eastern Chipmunks (*Tamias striatus*), American Robin (*Turdus migratorius*), songbirds, and an unidentified species of hummingbird. Other urban-adapted species likely to occur in the area are the Muskrat (*Ondatra zibethicus*), Raccoon (*Procyon lotor*) and Striped Skunk (*Mephitis mephitis*). Due to the proximity of the Connecticut River and presence of forest along its banks, wide-ranging carnivorous mammals also might occur locally, such as the Mink (*Mustela vison*).

6.2.3.6 Rare and Endangered Species in the CRREL Study Area. According to the New Hampshire Natural Heritage Inventory (1993), no federal- or state-listed rare, threatened, or endangered species of flora or fauna are known to occur within the CRREL property or in nearby, local areas (see Appendix Q).

6.2.3.7 Migratory Trustee Species In the CRREL Study Area. Migratory birds, protected by the Migratory Bird Treaty Act (16 USC 703-711), are considered as trustee resources under the jurisdiction of the U.S. Fish and Wildlife Service. No sightings of migratory birds (such as waterfowl) were made by Arthur D. Little field staff. An unidentified CRREL worker reported seeing ducks use the stormwater detention pond on several occasions, but not recently.

The fish fauna of the Connecticut River reportedly includes the Atlantic Salmon (*Salmo salar*), an anadromous freshwater species known to migrate up the river, which qualifies as a trustee resource/species under the shared jurisdiction of NOAA and the State of New Hampshire.

6.2.3.8 Symptoms of Ecological Stress In the CRREL Study Area. No visible stress symptoms were observed by Arthur D. Little staff in the vegetation of potentially affected on-site or off-site habitats. No visible stress symptoms were seen in vegetation growing in or near contaminated surface soils, sediments, or surface

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waters on the CRREL property. Even the off-site grassy swale, which originally drained the southwest quarter of the site and was a likely contaminant migration route from CRREL to the Connecticut River before construction of the detention pond in the 1980s, exhibited no visible symptoms of vegetation stress.

Based on casual, opportunistic observations by Arthur D. Little field staff, the health of the resident bird and mammal fauna appears to be normal. No evidence of stress or injury was reported to, or observed by Arthur D. Little's ecologist at the site. Although one CRREL worker commented that ducks stopped using the stormwater detention pond after the site began using the pond to hold "glycol" discharges, visible evidence of site-related injury to waterfowl or other birds has neither been observed by nor reported to Arthur D. Little's field personnel. No obvious symptoms of vegetation stress were evident either on the berms or in the bottom of this pond (see Figure 6-3A).

6.2.4 Assessment of Ecological Impact and Risk

6.2.4.1 Hazard Identification - Contaminants of Concern. Chemical contaminants of potential ecological concern (COCs) for which soil, sediment, and surface water samples were analyzed include VOCs, BTEX compounds, and TPH. Due to the TPH analytical method used, the chemical composition of this analyte class can generally be considered as similar to that of diesel oil (Fuel Oil No. 2). No analyses of the actual chemical composition of the "TPH fraction," of SVOCs, inorganics, or pesticides/PCBs were performed on any medium as part of the Phase II RI program.

Contamination Data Summaries: Except for surface water samples taken from the Connecticut River during Phase I of the RI, all of the contamination data evaluated were generated for the Phase II RI. Contamination data for the soil, sediments, and surface water in most of the on-site and off-site ecological exposure zones, described below and presented in Section 4.0 are summarized statistically by averaging non-detects (NDs) as one-half the detection limit, for those COCs detected at least once in each medium.

Summaries of analytical data for each medium include the arithmetic mean, minimum, and maximum detected concentrations, the location of the maximum detected concentration, and the frequency of detection within each exposure zone.

Site contamination data are summarized below and in the following tables for:

- Upland soils sampled at the CRREL site during Phase II (Table 6-3)

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Table 6-3: Hazard Evaluation for Surface Soil Contaminants

Compound	Units	Average	Minimum	Maximum	Location of Maximum	Depth of Maximum	# Detected/ # Samples	Toxicity Threshold Acute	Toxicity Threshold Chronic
Total Petroleum Hydrocarbons	mg/kg	26.67	13	320	SSS07	.5	6/18	•	•
1,1,1-Trichloroethane	mg/kg	0.14	0.75	0.75	SSS37	.5	1/18	•	•
Trichloroethene	mg/kg	6.78	120 (J)	120 (J)	SSS07	.5	1/18	•	•

Notes:

* Because of the variable and complex composition of petroleum hydrocarbons an assessment of potential toxic impacts cannot be determined without further speciation.

Protective soil criteria have not been established for 1,1,1-TCA or TCE. A discussion on the toxicity of 1,1,1-TCA and TCE to terrestrial vertebrates is found in Section 6.2.4.4.

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- Sediments and surface water of CRREL pond, sampled during Phase II (Table 6-4)
- Sediments and surface water collected from the Connecticut River, sampled during Phases I and II (Table 6-5)

No surface soil, sediment, or surface water samples were collected from the off-site swale, south of CRREL pond, which may have received contaminated runoff from the site prior to the construction of this pond. Phase I and II data for sediments and surface water of the Connecticut River are presented separately in Table 6-5, to permit historical comparisons of risk characterizations, because of the improvements in the quality and treatment of the site's effluent to the river between Phases I and II of the RI.

Soil Contaminants: VOCs were detected in only 1 of 21 samples of terrestrial surface soils of the CRREL facility, whereas TPH was detected in 6 of 19 surface soil samples. These VOCs include 1,1,1-trichloroethane (TCA) and TCE. The maximum VOC level detected was 120 µg/g (ppm) of TCE and the maximum TPH concentration was 320 µg/g (ppm), both of which occurred in sample SSS07 (Table 6-3).

Sediment Contaminants: The only VOC detected in CRREL pond sediments was a trace level (1.8 µg/g) of TCE in one of the two samples (Table 6-4) during RI Phase II. No VOCs were detected in river sediments during Phase I of the RI. TCE is the only VOC detected, in a single sediment sample from the Connecticut River during Phase II of the RI, at a very low concentration (Table 6-5). TPH was not detected in the pond sediments, but no analyses of TPH were performed on the sediments from the Connecticut River.

Surface Water Contaminants: Dichlorobenzene was detected in only one of two RI Phase II surface water samples from CRREL pond, at a level of 3.2 µg/L (ppi) (Table 6-4). No other VOCs were detected. During Phase I of the RI, TCE (maximum 220 µg/L) was detected at trace levels in only two samples of surface water from the Connecticut River, whereas neither TCE nor other VOCs were detected in the Phase II river water samples (Table 6-5). No analyses of TPH were performed on surface water samples from CRREL pond or Connecticut River.

6.2.4.2 Background Levels of COCs. No attempt is made to determine the relative incremental contributions to ambient concentrations of TCE detected in sediment and surface water of the Connecticut River, from upstream anthropogenic sources vs. the CRREL facility. Rather, all TCE, TCA, dichlorobenzene, and TPH detected in soil, sediments, and/or surface water of on-site and downgradient habitats are presumed to have been derived from activities at the CRREL site.

Table 6-4: Hazard Evaluation for Detention Pond

Compound	Units	Average	Minimum	Maximum	Location of Maximum	Depth of Maximum	# Detect/ # Samples	Toxicity Threshold [1]			Hazard Quotient		
								Acute	Chronic	Average	Acute	Chronic	Average
Surface Water													
Dichlorobenzene, nonspecific	ug/l	2.1	3.2	3.2	POND SW01	0-6"	1/2	1,120	763	0.002	0.003	0.003	0.004
Sediment													
Trichloroethene	mg/kg	0.96	1.80	1.8	PONDED2	0-6"	1/2	NA	NA	-	-	-	-

Note:

1. Toxicity values for surface water are the New Hampshire AWOC (1980). Currently there are no NOAA sediment guidelines for trichloroethene.

NA = Not available

Table 6-5: Hazard Evaluation of Connecticut River Contaminants

Compound	Units	Average	Maximum	Location of Maximum	Depth of Maximum	# Detect/ # Samples	Hazard Quotient		
							Acute	Chronic	Toxicity Threshold [1]
Surface Water									
RI Phase 1 Trichloroethene	ug/L	105.13	220	CONN SW2	0-6'	2/4	45,000	21,900	0.002
RI Phase 2 No detect	-	-	-	-	-	0/3	-	-	-
Sediment									
RI Phase 1 No detects	-	-	-	-	-	0/4	-	-	-
RI Phase 2 Trichloroethene	mg/kg	0.13	0.27	CONN SEC 02	0-6'	1/15	NA	NA	-

Notes:

1. Toxicity values for surface water are the New Hampshire AWQC (1990). Currently there are no NOAA sediment guidelines for trichloroethene.
- NA = Not available

6.2.4.3 Exposure and Impact Assessment. The following section is an integrated assessment of ecological exposures and impacts from CRREL-derived COCs. It includes a brief summary of the major ecological exposure and impact zones, primary exposure and impact pathways, and selected exposure and impact scenarios considered in this assessment.

Ecological Exposure and Impact Zones: As described above, the potential ecological exposure and impact zones of the CRREL study area include:

- The landscaped, upland grounds of the CRREL facility
- The on-site stormwater/wastewater CRREL pond
- The swale and mixed forest/meadows southwest of the facility that had received surface water runoff from the CRREL site (only prior to the construction of the detention pond)
- The Connecticut River habitats downgradient of the CRREL stormwater and wastewater outfall pipe

Ecological Exposure and Impact Pathways: Pathways by which exposures to COCs in soil, sediments, and surface water might adversely affect terrestrial, wetland, and/or aquatic flora and fauna typically include the following:

- Root uptake of water-soluble contaminants into vegetation from soil, sediment, and surface water
- Intake into foliage and/or inhalation by animals of vapors from VOCs released from soils, sediments or surface water into the atmosphere
- Transdermal uptake of contaminants into both invertebrate and vertebrate animals, from direct contact with soil, sediment, and/or surface water
- Respiratory intake of contaminants from surface water via gills of fish and/or transdermally by amphibians
- Direct ingestion of soil, sediment, and/or surface water by invertebrate and vertebrate species, either as part of their normal feeding behavior or inadvertently
- Direct ingestion of contaminated plant foods and/or animal prey by vertebrate species at higher trophic levels (i.e., food chain contamination)

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Only *direct exposures* of biotic communities to site-derived COCs in soil, surface water, and/or sediments of the terrestrial, wetland, and aquatic exposure zones are considered in this assessment. Food chain-mediated exposures of terrestrial and wetland fauna are not evaluated. However, since the AWQC and NOAA sediment guidelines account for direct toxicity as well as indirect, food chain-mediated contaminant effects on both invertebrate and vertebrate fauna, their use in the assessment of direct exposure risks does provide limited insight as to potential risks via aquatic food chains.

Ecological Exposure and Impact Scenarios: The primary focus of this ecological risk and impact assessment is the current and future risks from the exposure of local biota and ecosystems to site-derived contamination. A more limited evaluation is also presented of the long-term ecological impacts, if any, that may have resulted from the 1970 release of TCE and/or any other historical releases. The following ecological exposure and impact scenarios are considered in this assessment.

The most important, potential *terrestrial exposure* scenario considered here is the direct exposure of soil microbial and invertebrate populations to COCs in the surface soils of the CRREL property. Incidental ingestion of COC-contaminated soils by small mammals, however, also is briefly considered as a direct exposure scenario. Uptake of VOCs into vegetation and subsequent ingestion of contaminated plant foods by herbivores is a highly unlikely exposure scenario for the COCs found in physical media at CRREL and therefore is not considered. Potential historical impacts of CRREL activities on off-site terrestrial receptors, such as the swale and mixed forest south of CRREL pond, also are considered in this assessment.

The most likely *wetland exposure* is the direct contact of invertebrates and/or amphibians with the COCs detected in the surface water and sediments of CRREL pond. Direct ingestion and indirect, food chain-mediated exposures of vertebrate fauna to surface water and/or sediment contamination in the wetland of CRREL pond were not evaluated. Facility impacts to this on-site wetland, not related to COC releases, also were considered.

As with the wetland exposure zones, the only *aquatic exposure* scenarios evaluated in this study are direct contact of invertebrate, amphibian, and/or fish communities of the pond and river habitats with average and maximum COC concentrations in the surface water column and sediments. Indirect, food chain mediated exposures of local or migratory vertebrate fauna to COCs in surface water and/or sediments in aquatic habitats are not evaluated. For the Connecticut River, historical risks to pelagic biota of the river were evaluated using RI Phase I data for the water column, whereas current/future ecological risks were evaluated using only the RI Phase II surface water analytical data.

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6.2.4.4 Toxicity Assessment. The ecotoxicological data sources reviewed and effects measurement endpoints used in the toxicity assessment are summarized below.

Ecotoxicological Data Sources: Ecotoxicological data reviewed during endpoint selection include:

- NOAA Sediment Guidelines (Long and Morgan, 1991)
- New Hampshire AWQC documents
- Federal AWQC documents
- PCLs for surface soil used previously to assess risks to terrestrial vertebrates at Fort Devens (ADL, 1993)
- *Registry of Toxic Effects of Chemical Substances* (National Institute for Occupational Safety and Health (NIOSH), 1993)
- *Hazardous Substances Data Bank* (1993)
- *Handbook of Environmental Data on Organic Chemicals* (Verschueren, 1983)

Quantitative Dose-Response Data Considered in Toxicity Assessment: Federal and New Hampshire AWQC, aquatic & terrestrial ecotoxicity data, terrestrial PCLs, and/or NOAA sediment guidelines were reviewed for all organic compounds detected. Toxicity effects endpoints considered for use in the toxicity assessment included both acute and chronic thresholds for response. The endpoints selected from these data sources are briefly summarized below for soil, sediment, and surface water.

Soil: No toxicity data were available with which to assess risks at the individual level for terrestrial soil microbial and invertebrate communities. To assess risks to terrestrial vertebrates exposed to the two compounds detected in on-site surface soil, TCA and TCE, we reviewed available toxicity data from the literature as well as PCLs for terrestrial vertebrates. The PCLs, originally developed for the Fort Devens site in Massachusetts, are based on conservative toxicity thresholds and dietary uptake models. Acceptable concentration levels in soil were derived for over 50 chemicals for the Short-tailed Shrew, White-footed Mouse, American Robin, Garter Snake, Red Fox, and Red-tailed Hawk. However, neither the detected compounds, nor surrogate compounds are available from this list.

A literature review was conducted for TCA and TCE for small mammal oral toxicity data, such as the lethal dose for 50 percent of the test animals (LD_{50}) or sublethal developmental effects. Sources reviewed included the *Registry of Toxic Effects of Chemical Substances* (NIOSH, 1993), *Hazardous Substances Data Bank* (1993), and *Handbook of Environmental Data on Organic Chemicals* (Verschueren, 1983). Selected small mammal oral toxicity values for the two detected compounds are presented in Table 6-6 as estimates of the potential range of threshold values for several different effects endpoints.

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Table 6-6: Selected Oral Toxicity Values for Small Mammals

Compound	Species	Toxicity Value	Effects Endpoint
1,1,1-trichloroethane	rat	9,600 mg/kg	LD ₅₀
	mouse	6,000 mg/kg	LD ₅₀
	dog	750 mg/kg	LD ₅₀
	rabbit	5,660 mg/kg	LD ₅₀
	guinea pig	9,470 mg/kg	LD ₅₀
	rat	43 mg/kg	Developmental Abnormalities
Trichloroethylene	mouse	455,000 mg/kg	Tumorigenic
	mouse	912,000 mg/kg	Tumorigenic
	mouse	515,000 mg/kg	Tumorigenic
	rat	5,650 mg/kg	LD ₅₀
	mouse	2,402 mg/kg	LD ₅₀
	cat	5,864 mg/kg	LD ₅₀
	rabbit	7,330 mg/kg	LD ₅₀
	rat	2,688 mg/kg	Newborn effects
	rat	36,000 mg/kg	Newborn effects
	rat	1,140 mg/kg	Developmental Abnormalities
	mouse	182,000 mg/kg	Liver and kidney weight
	mouse	3,360 mg/kg	Liver weight

Source: NIOSH, 1993 (on-line database).

Sediment: TCE was the only compound detected in sediment. Endpoints initially reviewed for toxicity assessment of TCE at the community level for benthic invertebrates, living in contact with pond, or river sediments were the NOAA sediment guidelines (Long and Morgan, 1991). These guidelines are applicable to both marine and freshwater benthic organisms. At this time NOAA has not established a guideline for TCE. We therefore reviewed sediment criteria from the New York State Department of Environmental Conservation and the New Jersey Department of Environmental Protection. However, neither of these agencies has established an ecologically protective sediment criterion for TCE. Therefore, a quantitative assessment of potential risks from exposure to TCE in sediments was not possible.

Surface Water: Aquatic endpoints selected for toxicity assessment at the community level for pelagic biota such as invertebrates, fish, and amphibians are the acute and chronic New Hampshire AWQC adopted effective August 3, 1990. These criteria are considered to be protective of entire, diverse aquatic communities of the water column, including algae, invertebrate and vertebrate fauna. COC-specific endpoints for surface water are the acute and chronic freshwater AWQC for those COCs detected in surface water of the detention pond and/or Connecticut River:

- Dichlorobenzenes AWQC: acute = 1,120 µg/L; chronic = 763 µg/L
- Trichloroethylene AWQC: acute = 45,000 µg/L; chronic = 21,900 µg/L

6.2.4.5 Risk Characterization. COC-specific risk estimates, or HQs, are calculated by dividing the observed concentration in each medium by the COC-specific effects measurement endpoint for that medium (e.g., AWQC). As noted previously, an HQ of 1.0 or greater indicates potential ecological risk. HQs are calculated, when possible, for the average and maximum detected COC concentrations in the soil, sediment, and/or surface water of each ecological exposure zone. Although HQs are typically summed to produce HIs, as a measure of the aggregate risks to biotic communities from mixtures of two or more COCs, this step is not necessary in the current assessment because there is only one COC for which endpoints are available in each medium. The quantitative ecological risk estimates are summarized for each medium/zone in Tables 6-3, 6-4, and 6-5. A brief discussion of the quantitative risks and their qualitative ecological significance is provided below for the biological communities of each exposure zone.

Surface Soils: Due to the ability of soil microbial communities to biodegrade TCE, and the relatively low levels of TCE found in surface soils, both direct exposure risks to microbial communities and indirect, detrital food chain exposure risks are unlikely to be significant at CRREL. Since the detected COCs do not bioaccumulate significantly within either the vegetation or invertebrates of upland soils, food

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chain-mediated exposures of plant- and/or invertebrate-eating animals also are unlikely to be significant.

An evaluation of the relationship between toxicity and reported on-site compound concentration was conducted to determine the level of soil ingestion required to induce toxic response. For TCA we estimate a worst-case scenario by using the rat toxicity threshold for developmental abnormalities of 43 mg per kilogram of body weight, as a surrogate toxicity threshold for the eastern cottontail rabbit (*Sylvilagus floridanus*), which occurs on site. We also assumed that the TCA concentration in all soil ingested is equal to the maximum detected concentration of 0.75 mg/kg. Based on these parameters, a 1 kilogram rabbit would need to ingest 57.3 kg of soil per day, many times its body weight, to receive a toxic oral dose.

For TCE we once again estimated a worst-case scenario by using a sublethal, oral toxicity threshold of 1,140 mg/kg for developmental abnormalities in the rat, as a surrogate toxicity threshold for the rabbit. In order to receive this toxic dose, a rabbit would have to ingest 9.5 kg of the most contaminated upland soil (TCE = 120 mg/kg). Similarly, based on a rabbit oral LD₅₀ of 7,330 mg/kg-body weight for TCE, a 1 kilogram rabbit would have to ingest 61 kg/day of the most TCE-contaminated soil to elicit a lethal response in 50 percent of the exposed population. Since it is probably impossible for a rabbit to incidentally ingest between 10 and 60 times its own body weight of the most contaminated soil during one day of feeding on upland vegetation, no further quantitative evaluations of risks from TCA and TCE were conducted.

Sediments: Since NOAA has not established ecologically protective sediment guidelines for TCE, the relative risks to benthic invertebrates of the pond and river sediments cannot be quantified. However, exposure of benthic biota to sediment pore water contaminant concentrations is a key exposure pathway by which sediment effects are mediated. A comparison of the chronic, freshwater AWQC for TCE (21.9 ppm) to the maximum theoretical sediment pore water concentration for TCE in the detention pond (PONDSED02, 1.8 mg/kg TCE) indicates a lack of significant risk to benthic organisms from this maximum TCE level. The pore water concentration is calculated using the following equation:

$$C_w = C_s / (K_{oc} * f_{oc})$$

where:

- C_w = Concentration of compound in water ($\mu\text{g/L}$)
- C_s = Concentration in sediment ($\mu\text{g/kg}$)
- K_{oc} = Organic carbon partition coefficient (kg/L)
- f_{oc} = Function of organic carbon in soil (kg/kg)

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By conservatively assuming 1.0 percent total organic carbon content of the sediments, this detected sediment concentration would result in a maximum pore water TCE concentration of 1.6 mg/L (ppm).

Surface Water: Both the average and maximum HQs for all COCs in all exposure zones are two or more orders of magnitude less than 1.0, indicating no ecological risk. The low levels of TCE and dichlorobenzene detected in the surface water of each exposure zone, therefore, pose no ecological risks to biological communities of the water column, in either wetland or aquatic habitats located on site (pond) or downstream in the Connecticut River.

Background Risks: No estimates were made of ecological risks from background soil, sediment, and/or surface water levels of COCs. Since road runoff typically contains petroleum hydrocarbons (TPH), BTEX compounds, and related VOCs (EPA, 1983; FHA, 1981), however, part of the (insignificant) aquatic ecological risk from COCs in the Connecticut River downstream from the CRREL outfall pipe is probably attributable to upstream, non-CRREL pollution sources.

6.2.4.6 Uncertainty Analysis. Uncertainty in this ecological impact and risk assessment is associated with the possibility that the CRREL study area has not been sufficiently characterized with respect to site-derived, organic and/or inorganic contamination levels in soils, sediments, and/or surface water of the on-site or off-site, upland, pond/wetland, and/or river habitats. This uncertainty is greatest for inorganic and semivolatile organic chemicals, for which no analyses were performed as part of the Phase II RI.

Other data gaps that contribute to uncertainty in this assessment include:

- The absence of soil samples and data for the off-site swale south of the detention pond, which historically carried runoff from the site to Girl Brook
- The lack of complete petroleum hydrocarbon analyses for surface water of the on-site detention pond and Connecticut River, which otherwise could have been compared with AWQC or other toxicity data for fuel oils and/or related petroleum hydrocarbons. A related uncertainty arises from the lack of analytical data on the chemical composition of contaminant mixtures detected as "TPH" in surface soils and sediments so that an ecotoxicity assessment for TPH levels in surface soils and sediments is not possible.

However, assuming that the contamination data collected in the Phase II RI are representative of the types and levels of contaminants at these unsampled or incompletely analyzed locations, no significant incremental risk to on-site or off-site biota and ecosystems would be expected.

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6.2.4.7 Conclusions. As summarized briefly below, past and current releases or discharges of environmental contaminants from the CRREL facility appear neither to have caused any adverse, long-term ecological impacts, nor to pose any current or future, contamination-mediated ecological risks to on-site or off-site biota and ecosystems.

Ecological Impacts: No visible stress symptoms were seen in any of the terrestrial, wetland, or aquatic habitats that currently receive, or may have been historical receptors for, contaminants released from the CRREL facility. Although the on-site pond/wetland area in the southwest corner of the site serves as a detention area for both stormwater and experimental solutions prior to discharge to the river, the flora of the pond bottom and embankments appeared healthy. The off-site, vegetated swale located south of this pond, which is likely to have received contaminated surface runoff from the site after the 1970 TCE release, also exhibits no vegetation stress symptoms or other obvious features indicative of long-term ecological impacts.

Ecological Risks: Soil, sediment, and surface water contaminants attributable to activities at the CRREL site currently appear not to pose significant risk to terrestrial, wetland, or aquatic biota and ecosystems, found on site or in the downstream areas of the Connecticut River that receive surface water discharges from the site. As discussed above, the oral ingestion toxicity endpoints of TCA and TCE are sufficiently high in terrestrial vertebrates such as mice, rabbits, and rats, that even the maximum detected levels in terrestrial surface soils at CRREL pose no significant risk to these mammals. Similarly, the low levels of TCE detected in river and pond sediments also pose no significant risk to benthic biota of these habitats. No VOCs were detected in the surface water of the Connecticut River downstream from the site's effluent outfall during Phase II of the RI, and even the maximum TCE level detected in river water during the RI Phase I investigation is two orders of magnitude below the chronic, freshwater AWQC for TCE.

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7.0 Conclusions and Recommendations

7.1 Summary and Conclusions

7.1.1 Nature and Extent of Contamination

The primary contaminants at the site are TCE, PCE, toluene, and TPH. Breakdown products of the chlorinated compounds are locally present in lesser concentrations, as are other compounds associated with site activities (Freon 11, MEK, ethylbenzene, xylene, dichlorobenzene). The primary contaminants are present in the soil vapor, soil, and ground water at the site. Primary contaminants were not detected in the surface water in CRREL pond or the Connecticut River during the Phase II sampling. TCE was detected at low concentrations in one sediment sample from CRREL pond, and one from the Connecticut River.

The soil at CRREL is generally very fine-grained sand and silt interpreted to have been deposited in a glacial lake basin. The lake sediments locally contain lenses of silt and clay that are laterally continuous for up to several tens of feet. Layers of coarser-grained materials (medium sands) are locally present, and become more prevalent in the lower portion of the overburden sequence. The esker, which trends north-south at the west end of the site, is composed of a series of alternating layers of fine to very coarse, texturally immature sands and gravel. The interface between the esker and the lake sediments appears to be sharp. The primary contaminants, with the exception of TPH, are not well adsorbed onto the soil grains. At contaminant source areas, soil pores contain vapors of primary contaminants and are present as deep as the water table at AOCs 2, 9, and 13, and as deep as 40 feet at AOC 15. Soil vapor wells were installed in AOCs 2, 9, 13, and 15 through zones of high soil vapor readings.

The bedrock surface at CRREL is irregular and ranges in depth from 65 feet below ground surface at the west side of the site to over 250 feet in the center of the site at AOC 9. Limited data from borings and geophysical surveys indicate that a north-south trending low in the bedrock surface, subparallel to the esker, is present in the central portion of the site. Oriented cores show well defined water-bearing fracture trending both northeast and northwest at moderate to steep dips. The fractures are very common in the upper 5 feet of bedrock, but quickly reduce in density to only a few per 10 feet. The fractures are found as individual breaks both parallel and perpendicular to foliation with apertures of up to 1 inch. Individual fractures have relatively high hydraulic conductivities, but overall the bedrock has relatively low hydraulic conductivity. Hydrogeologic studies of the bedrock aquifer on the west side of the river also identify northeast and northwest trending water-bearing fractures.

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Ground water at CRREL occurs in the lake sediments, esker, and fractured bedrock. Ground water flow patterns at the site are largely influenced by the drawdown of the production wells in the esker near the west side of the site. Under normal pumping conditions, the wells create a radial zone of influence that encompasses most of the site east of the production wells. Ground water on the west side of the esker is controlled by the water level in the adjacent Connecticut River, indicating that the esker is recharged by the river. Additional recharge to the esker at the site may come from the north where the esker intersects the river. Results from hydraulic conductivity testing in the monitoring wells indicate that the lake sediments and fractured bedrock are much less permeable than the esker sediments.

Samples from monitoring and production wells in each of the geologic regimes have shown primary site contaminants. The highest contaminant concentrations were detected in the overburden near the Ice Well. Concentrations of TCE at this location have exceeded 1 percent of its solubility limit, indicating the potential for DNAPL. Production well CECRL03 was the only well to yield samples with no detectable concentrations of VOCs. The low levels of TCE identified in monitoring well CECRL20, installed as a background well near the southern boundary of the site, are likely due to the effects of production wells CECRL03 located at the south of the site in the esker. Pumping of well CECRL03 creates a zone of influence that draws ground water from throughout the site, including potential source areas, toward the southern portion of the site and well CECRL20. The source of contaminants in background well couplet CECRL07 and CECRL13, near the northeast corner of the site, is not known, however, an off-site source cannot be ruled out. Samples from the production wells showed no TPH or toluene contamination (but did have TCE and PCE concentrations). Bedrock wells generally showed lower concentrations than their overburden couplets. During the five rounds of sampling only one compound, TCE, was detected at the Hanover standby well once at a concentration just above detection limit, yet well below the MCL.

7.1.2 Fate and Transport

The primary contaminants are present as vapors in the soil pores, dissolved in ground water, and possibly as a separate phase in ground water. The contaminants were released directly to the soil or ground water from source areas including AOCs 1, 2, 9, 10, 13, 15, and 16. In the soil pores the vapors are located in close proximity to the source areas, with limited lateral migration due primarily to dispersion. The vapors extend to the water table at several of the AOCs, indicating that there is significant vertical transport. Dissolved contaminants in ground water are transported through the overburden primarily by advection. Locally, in areas of low permeability or clay lenses, dispersion may be the controlling transport mechanism. Contaminants are likely moving faster through the base of the overburden where soil is more permeable, and in connection with the esker sands. Density controlled plumes may be developed at the source areas and may sink to the base of the aquifer and enter the

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basal esker sands or infiltrate into the fractures or continue to flow along bedrock topography to low spots or impermeable boundaries. If present, DNAPL will tend to sink to the bottom of the aquifer, or other impermeable layer and create a secondary contaminant source deep in the aquifer. DNAPL will enter fracture zones and be transported in the direction of the water-bearing fractures. Upward gradients, identified locally at CRREL and on the west side of the river, may transport contaminants back up into the overburden aquifer.

Some degradation of chlorinated compounds appears to be taking place to a limited extent in the subsurface. At several well locations, intermediate breakdown products of PCE and TCE are identified. The presence of chloroform may indicate degradation of chlorinated compounds. No direct evidence for biotic degradation was observed.

7.1.3 Risk Assessment

A human health risk assessment was conducted using Phase I and Phase II data for surface soils, surface water, sediments, and ground water. Potential human exposure pathways exist for surface soils at the CRREL facility, and for surface water and sediments of the Connecticut River. Because concentrations detected in these media are low, the frequency of detection is low, and exposures to these media are expected to be infrequent, adverse health effects are not likely to occur due to exposure to surface soils, or to surface water and sediments of the Connecticut River. In fact, there were no chemicals detected in the Phase II Connecticut River surface water sampling. Exposures to the surface water and sediments of CRREL pond on site are unlikely, or would occur very infrequently, and the concentrations and frequency of detects in CRREL pond are low. There are no current human exposures to ground water from beneath the site, and future site use is expected to remain the same. In addition, the facility and all residences in the area of the facility are connected to the municipal water supply of Hanover, which is not associated with the ground water beneath the site. In conclusion, because detected chemical concentrations on the site are low, or because no current or future human exposure pathways exist, the human health risks associated with the CRREL facility are likely to be non-existent or low.

The ecological impact and risk assessment was performed to identify any visible impacts on local ecological resources and potential risks of adverse ecological impacts to the environment from the contamination. The assessment consisted of reviewing the ecological resources of the area from published maps, documents, and field surveys, assessing the ecotoxicity using available guidelines and contaminant specific ecological data, and assessing the risk based on calculation of contaminant specific hazard quotients and aggregate hazard indices for resident biotic communities. The assessment identified no on-site wetland or aquatic habitats within which fauna are likely to be exposed. The only on-site habitat was the lawns, trees, and plantings around the buildings. Off-site habitats included the upland wooded habitat between CRREL and the river, landscaped residential areas, open fields, and

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the Connecticut River. Potential receptors include a wide range of fauna typical to the area, but includes no rare or endangered species.

No visible stress symptoms were observed in any of the terrestrial, wetland, or aquatic habitats that currently receive, or may have been historical receptors for contaminants released from CRREL. Contaminants identified in soil, sediment, and surface water do not appear to pose significant risk to terrestrial, wetland, or aquatic biota on site or off site.

7.2 Recommendations

Based on the results of the remedial investigation, several recommendations are made for future actions at the site. These include actions that would reduce contaminant concentrations at source areas, control migration of contaminated ground water, remove contaminants from captured ground water, and monitor the quality of the ground water in the area. These recommendations are readily implemented by relying on existing systems and, when performed together, will provide effective management and control of the contamination. Each of these recommendations is described below.

7.2.1 Evaluation and Implementation of Source Area Mitigation

An evaluation of potential treatment technologies to remove, treat, or contain contamination at source areas should be performed to identify cost-effective remedial actions that will reduce and control further releases of contaminants at the source areas. The evaluation would include methods to reduce contaminant concentrations in soil and ground water using existing systems (monitoring wells, soil vapor wells, ground water treatment facility). Once identified, the selected remedial actions would be implemented. Evaluation of remedial actions would be recommended for AOCs 2, 9, 13, and 15.

7.2.2 Production Well Optimization

The existing ground water flow pattern throughout the site is controlled by the operation of the five production wells in the esker. The water produced from these wells, which operate continuously, is treated to remove iron, manganese, and volatile organic compounds. The extraction of ground water currently occurring at CRREL as part of regular ongoing operations provides good control of the contaminated ground water in the overburden, because the production wells are completed in the esker east of the bedrock high, which acts as a barrier to recharge from the river. In addition, the treatment of the extracted ground water removes contaminants. The existing production well flow rates, however, could be optimized to maximize containment of contaminated ground water and removal of contaminants. The optimization of the production wells would involve adjustment of the pumping rates or pumping periods based on results from an analysis of the hydrologic system.

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7.2.3 Ground Water Monitoring

Selected wells at CRREL and in its vicinity should be monitored semiannually. Wells at CRREL should be monitored to evaluate the effectiveness of the ongoing remedial actions, and provide early detection of changes in contaminant concentrations in areas of interest. Selected off-site wells should be monitored to provide early detection of contaminants and monitor changes in off-site conditions. The following sampling locations are recommended:

On-site

- Production wells
- Source area wells (if remedial actions are implemented)
- Perimeter wells (CECRL12, CECRL16/17, CECRI.7/13, CECRL20)

Off-site

- Town of Hanover standby well
- Goodrich, Peacock, and Britton residential wells (after conversion to monitoring wells)
- Pinello residential well (northwest of CRREL, in Norwich, Vermont)
- James Forcier, Lewis, and Sacks residential wells (southwest of CRREL in Norwich, Vermont)

The Pinello, James Forcier, Lewis, and Sacks residential wells on the west side of the Connecticut River are proposed for monitoring because they are the closest readily available monitoring points west of CRREL (Figure 7-1). Monitoring data from these wells, when reviewed in association with the Goodrich, Peacock and Britton wells, will help to better understand the rate and direction of contaminant migration in fractured bedrock.

It is recommended that ground water monitoring include measuring water levels and collecting samples for volatile organic compound analysis. Sample analysis procedures should be consistent with those used in the RI to ensure data quality.

7.2.4 Summary of Recommended Actions by AOC

Recommendations for each of the AOCs are described below and summarized in Table 7-1.

AOC 1: We recommend that no further action be taken at this location. Ground water contamination that may be due to releases in this area will be addressed in conjunction with the actions taken at AOC 9, which is located immediately adjacent to AOC 1, and, as part of the sitewide ground water containment system associated with the production wells.

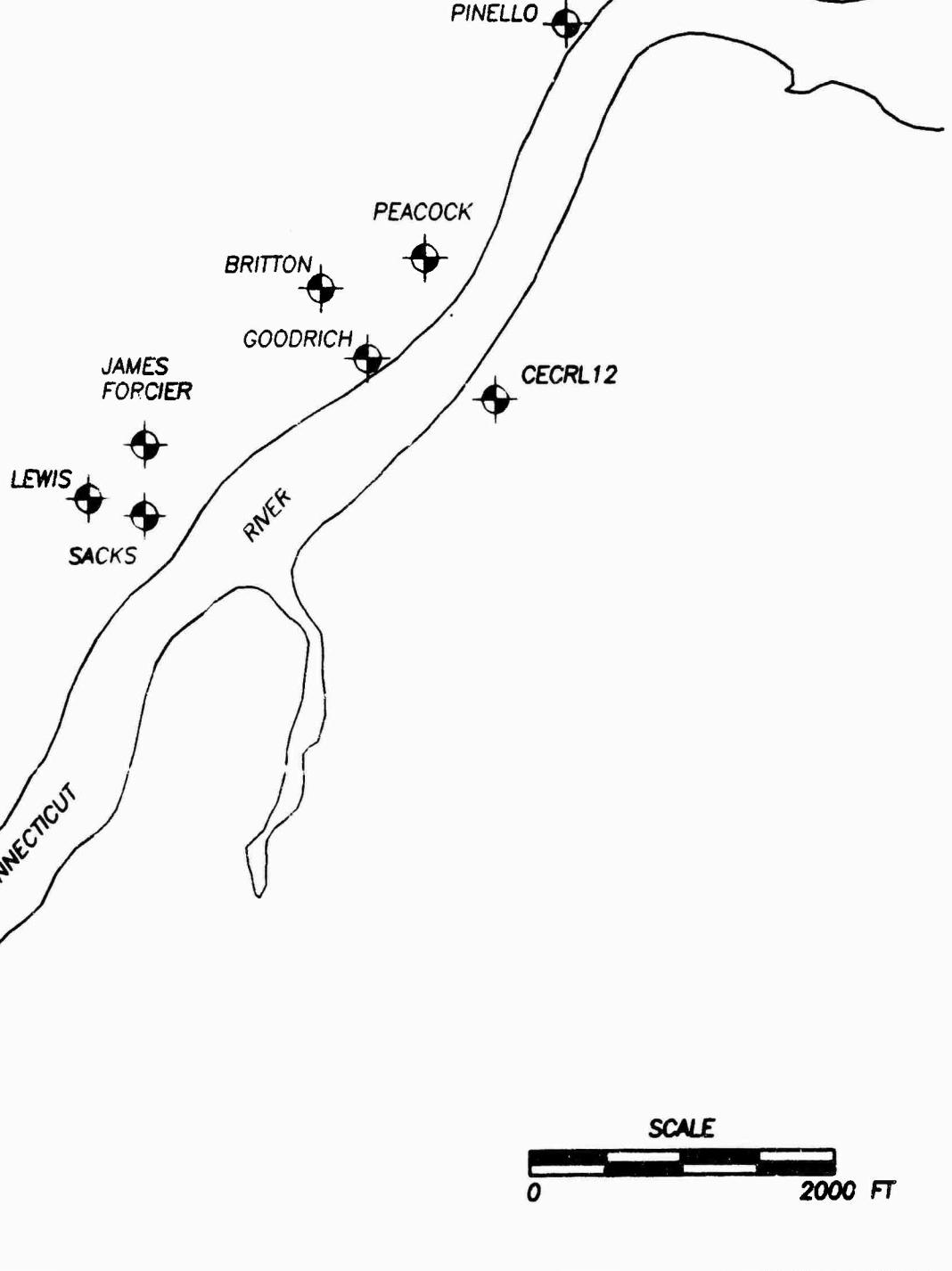
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Table 7-1: Summary of Recommended Actions for CRREL AOCs

Area of Concern	Recommended Action
AOC1	No further action required Ground water treatment will be included as part of the sitewide system and actions taken at AOC9
AOC2	Evaluate source control treatment
AOC3	No further action required
AOC4	No further action required
AOC5	No further action required
AOC6	No further action required
AOC7	No further action required
AOC8	No further action required
AOC9	Contaminant Removal from Ice Well Evaluate source control treatment
AOC10	No further action required Ground water treatment will be included as part of the sitewide system
AOC11	No further action required Ground water treatment will be included as part of the sitewide system
AOC12	No further action required
AOC13	Evaluate source control treatment for soil Ground water treatment will be included as part of the sitewide system
AOC14	No further action required
APC15	Evaluate source control treatment
AOC16	No further action required

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USAEC

DATE:
MAR. 1994

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SCALE:

AS SHOWN

TITLE:

FIGURE 7-1

PROPOSED MONITORING POINTS
ON WEST SIDE OF CONNECTICUT RIVER

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AOC 2: We recommend that treatment technologies for soil and ground water source control be evaluated for this location. The goal of any future actions at this location would be to control and reduce contaminants that may be sources of continuing releases.

AOC 3: We recommend that no further action be taken at this AOC. The tank was removed in 1989, and soil gas investigations showed no indication of contamination at this location.

AOC 4: We recommend that no further action be taken at this location. There have been no releases from tanks at this location, and soil gas investigations showed no indication of contamination.

AOC 5: We recommend that no further action be taken at this location. There have been no known releases from this location, and during construction of the new Remote Sensing Facility at this location, no indications of contamination were observed.

AOC 6: We recommend that no further action be taken at this location. Samples taken from this area during the Phase I investigation did not reveal contamination.

AOC 7: We recommend that no further action be taken at this location. The tank and associated soil were removed in October 1993. Soil gas investigations in the area did not reveal contamination.

AOC 8: We recommend that no further action be taken at this location. The tank no longer exists at this location, and soil gas investigations indicated no contamination.

AOC 9: In addition to removal of the contents of the Ice Well, which is planned for this year, we recommend that local treatment of soil and ground water be evaluated to control sources of contamination that may be present at this location.

AOC 10: We recommend that no further action be taken at this location. There is no risk associated with the soil contamination detected at this location (0.007 ug/g TCE detected at 10 feet), and ground water contamination from surface spills that may have occurred in this area will be controlled and treated by the existing sitewide ground water treatment system associated with the production wells.

AOC 11: We recommend that no further action be taken at this location. Ground water contamination from surface spills that may have occurred in this area will be controlled and treated by the existing sitewide ground water treatment system associated with the production wells.

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AOC 12: We recommend that no further action be taken at this location. There were no known releases from this location, and soil gas investigations did not reveal contamination in this area.

AOC 13: We recommend that treatment of contaminated soil be evaluated at this location to reduce and control the contaminant source. Contaminated ground water in this area will be controlled and treated by the existing sitewide ground water treatment system associated with the production wells.

AOC 14: We recommend that no further action be taken at this location. This AOC is located inside the building, and if releases were to have occurred in the past, they would not affect soil or ground water.

AOC 15: We recommend that the localized treatment of contaminated soil be evaluated at this location to reduce contaminant sources. Contaminated ground water in this area will be controlled and treated by the existing ground water treatment system associated with the production wells.

AOC 16: We recommend that no further action be taken at this location. Samples taken from this area during the Phase I investigation did not reveal contamination. This is the location of the permanent ground water treatment facility that was constructed in 1993. In addition, any ground water contamination in this area would be controlled and treated by the existing ground water extraction and treatment system associated with the production wells.

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